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Dielectric Constant and Loss Data

W. B. Westphal and A. Sils
Massachusetts Institute of Technology

Technical Report AFML-TR-72-39

April 1972

Approved for Public Release, Distribution Unlimited

Air Force Materials Laboratory
Air Force Systems Command
Wright-Patterson Air Force Base, Ohio

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13. ABSTRACT

The main body of this report includes data on high-temperature materials, primarily organic crystals, ceramics and glasses. Additional sections include plastics and materials with less heat resistance.

This report is mainly a recompilation of data on dielectric materials measured after Vol. VI of Tables of Dielectric Materials, 1958. Data from progress reports and the following L.I.R. and Air Force technical reports are included: Tech. Rep. 114, Tech. Rep. 182, Tech. Rep. 203, AFML-TR-65-396, AFML-TR-70-138, AFML-TR-71-66.

Data on ferroelectrics measured following the Tables of Dielectric Materials are excluded. The index is intended to be a complete reference to Vols. IV, V, and VI of Tables as well as the present report (P.R. in index).

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Dielectric constant						
Dielectric loss						
Electrical permittivity						
High-temperature materials						
Inorganics						
Minerals						
Rocks						
Organic materials						
Plastics						
Liquids						

DIELECTRIC CONSTANT AND LOSS DATA

W. B. Westphal and A. Sils

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FOREWORD

This report was prepared by the Massachusetts Institute of Technology, Laboratory for Insulation Research, Cambridge, Massachusetts, under USAF Contract F33615-71C-1274. This Contract was initiated under Project No. 7371, "Exploratory Development in Electrical, Electronic, and Magnetic Materials," Task No. 737101, "Dielectric Materials." The work was administered under direction of the AF Materials Laboratory, with Mr. W.G.D. Frederick (AFML/LPE) acting as project engineer.

This report was compiled from February 1, 1971 to January 31, 1972, and was submitted in February 1972 by the authors for publication.

This technical report has been reviewed and is approved.

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Materials Physics Division
Air Force Materials Laboratory

ABSTRACT

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DIELECTRIC PARAMETERS

Dielectric parameters in the present report have the following notation:

κ', $\varepsilon'/\varepsilon_o$, dielectric constant relative to vacuum

κ'', $\varepsilon''/\varepsilon_o$, dielectric loss factor relative to vacuum

tan δ, or tan δ_d, dielectric loss tangent (dissipation factor)

κ_m', μ'/μ_o, magnetic permeability relative to vacuum

κ_m'', μ''/μ_o, magnetic loss factor

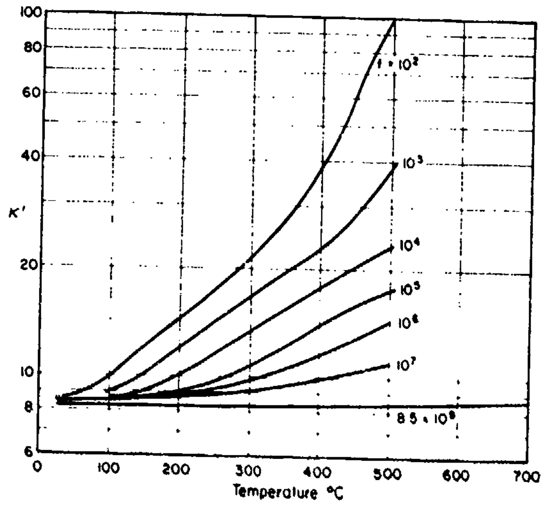
tan δ_m, magnetic loss tangent

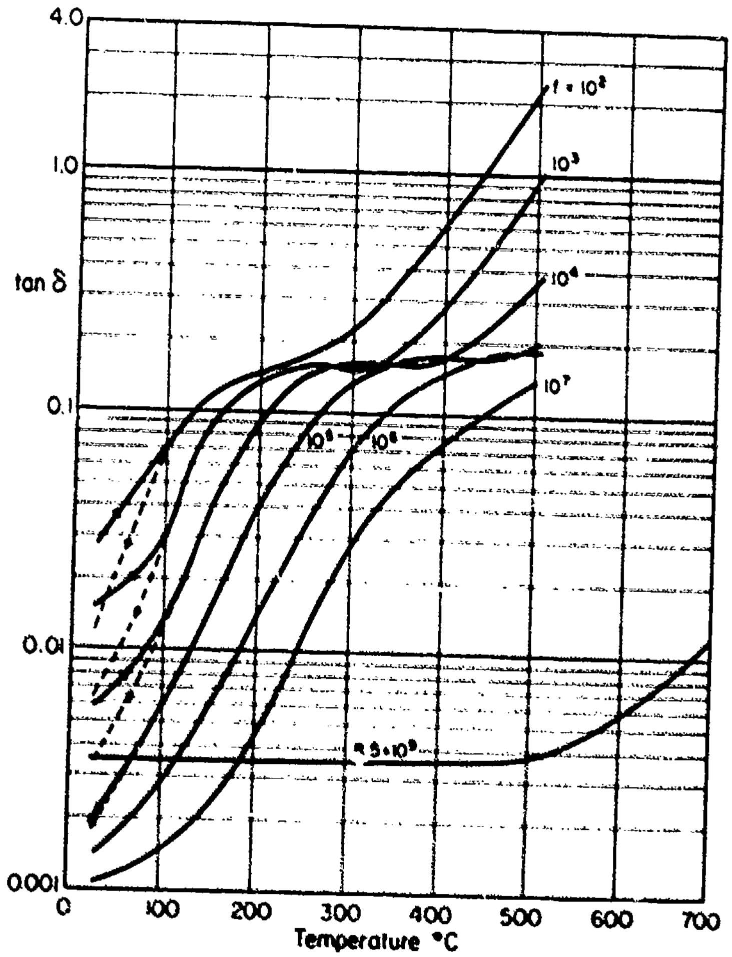
σ, a.c. volume conductivity in mho-cm

ρ, a.c. volume resistivity in ohm-cm

Aluminum nitride, hot-pressed,
at 8.5 GHz, 25°C, $\kappa' = \pm 0.1$

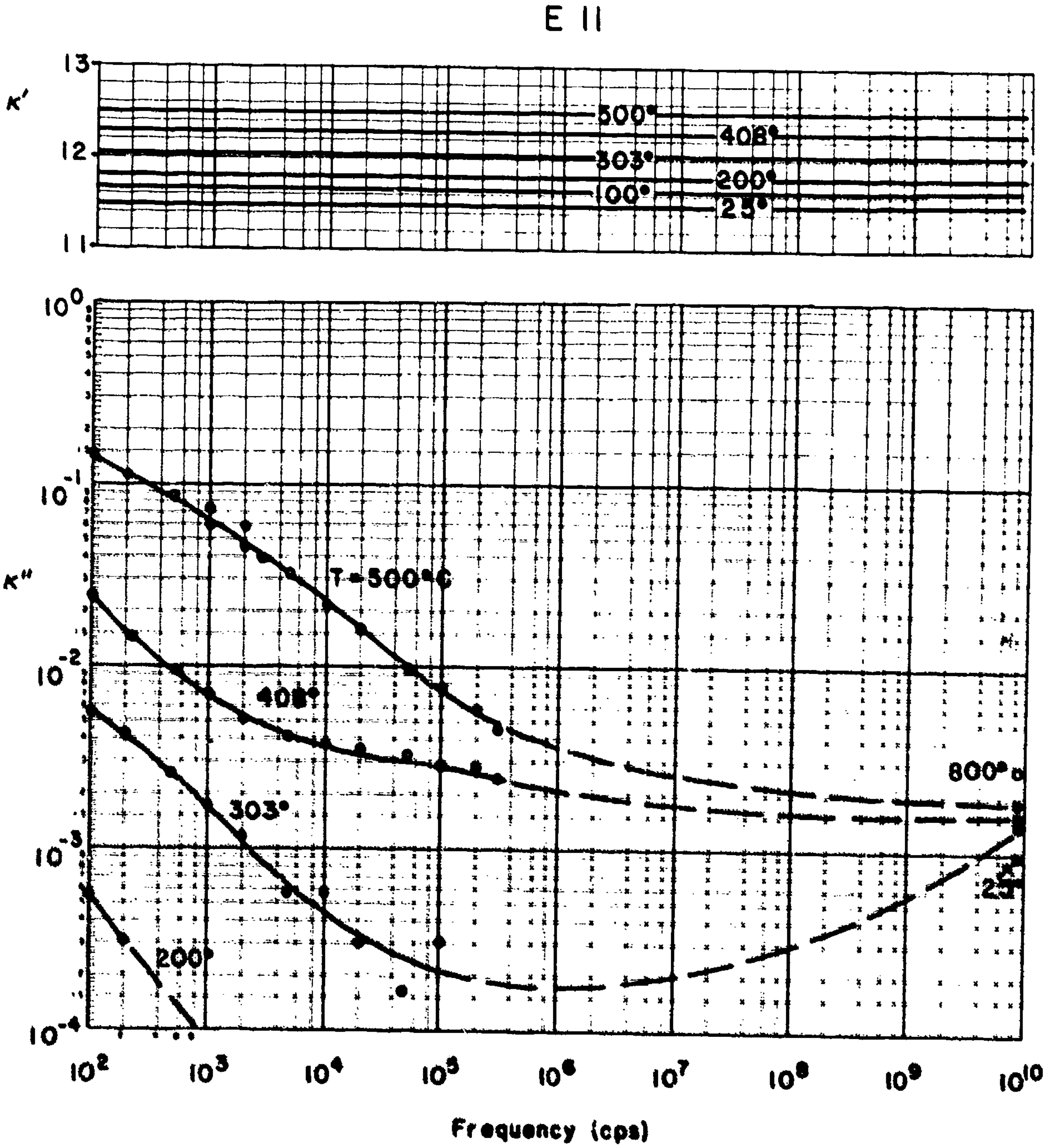
The Carborundum Co.

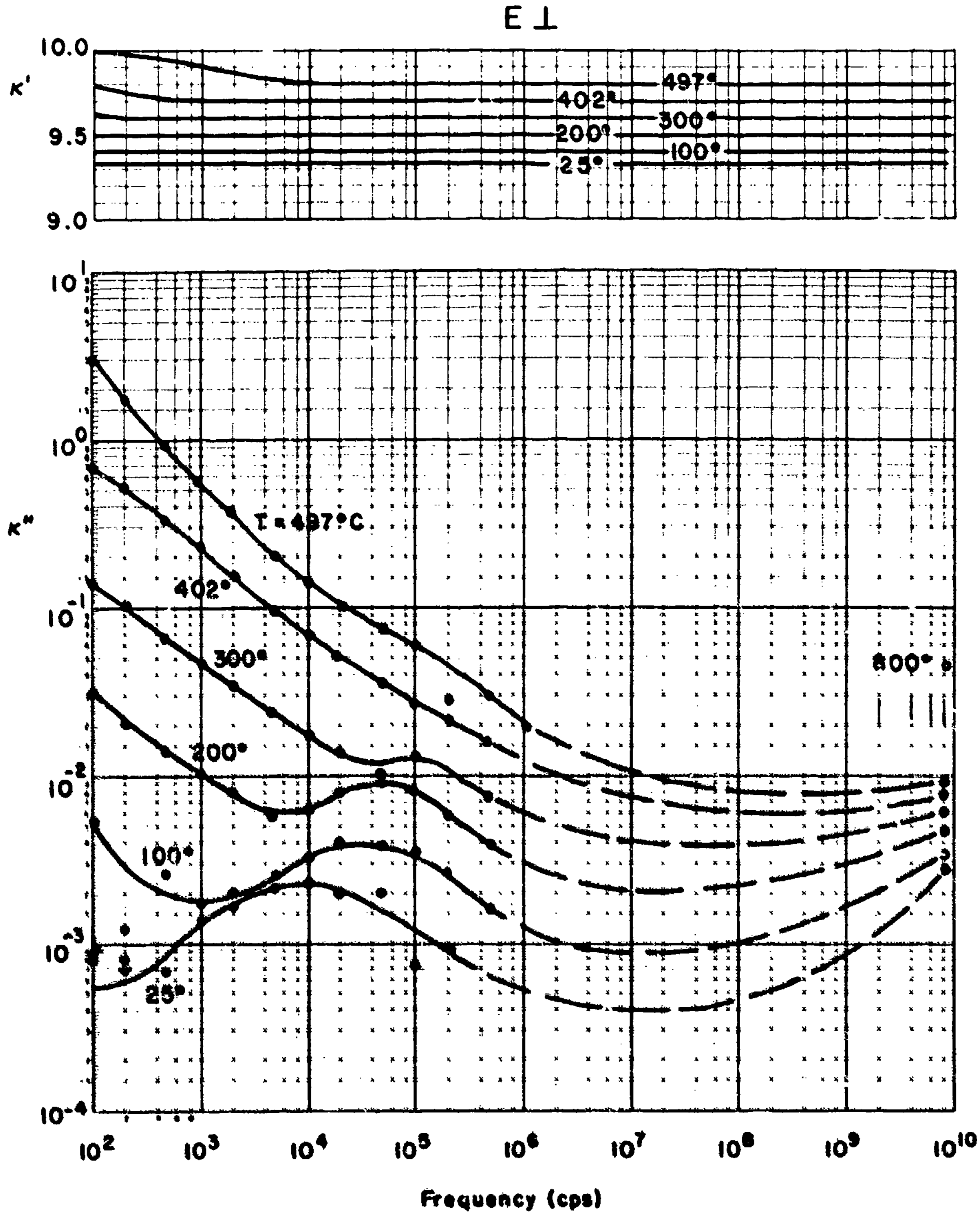




Al_2O_3 single-crystal sapphire, low frequency peak dispersion due to silver diffusion. To be re-evaluated to higher temperatures with platinum electrodes.

The Linde Air Products Co.




E ⊥
10.0
κ'
9.5
9.0
497°
402°
300°
200°
100°
25°
10¹
10⁰
κ"
10⁻¹
10⁻²
10⁻³
10⁻⁴
T = 497°C
402°
300°
200°
100°
25°
800°
10²
10³
10⁴
10⁵
10⁶
10⁷
10⁸
10⁹
10¹⁰
Frequency (cps)

Aluminum oxide, single crystal

Sapphire Al_2O_3

Density at 25°C = 3.9840 g/cm^3

Union Carbide
Electronics Division

Loss tangents at 8.5 GHz, 25°C:

$E \perp c$, <.00002

$E \parallel c$, <.00005

Dielectric constants at 3 GHz:

T°C	$E \perp c$	$E \parallel c$
25	9.390*	11.584*
-75	9.292	11.433
-195	9.257	11.357

Freq. 3.45-3.33 GHz, $E \perp c$

T°C	κ	tan δ
25	9.39	< .0001
80	9.41	< .0001
240	9.49	< .0001
377	9.62	< .0001
526	9.83	< .0001
617	9.95	< .0001
713	10.08	< .00015

Variation of dielectric constant at 25°C with inclination of electric field direction with respect to optic axis was calculated from elliptic polarization function:

$$\kappa = \left[\frac{11.584^2 \times 9.39^2(1 + \cot^2\theta)}{11.584^2 + 9.39^2 \cot^2\theta}\right]^{1/2},$$

θ	κ
10	11.494
20	11.246
30	10.895
40	10.507
50	10.1295
60	9.820
70	9.584
80	9.439

Average κ for random oriented full-density ceramic:

$$\kappa_{av} = 10.071 \text{ from } \kappa_{av} = (9.30 \times 9.39\ 11.584)^{1/3}$$

or 10.121 for approximate value (11.584+2 9.390)/3.

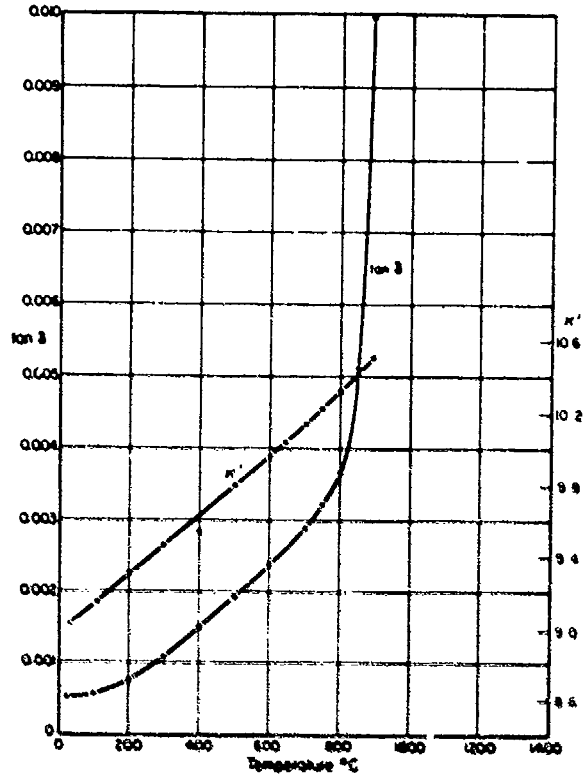
---

* These values are in reasonable agreement with optically measured values of 11.56 and 9.406 [E.E. Russell and Bell, J. Opt. Soc. Am. 57, 543 (1967)].

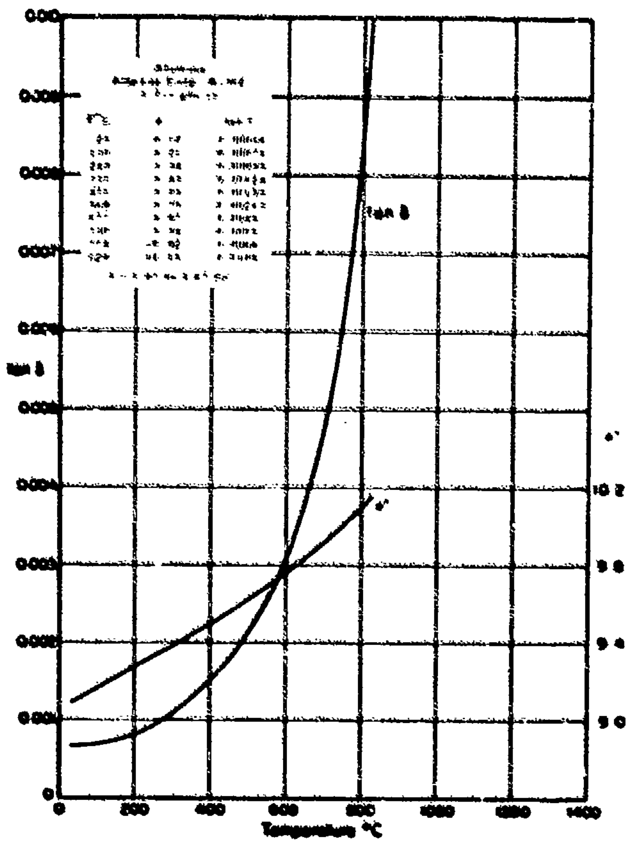
Aluminum oxide
Multicrystalline (alumina)

Alberox Corp. A-950
95% Al_2O_3
density: 3.663 g/cm^3

T^oC	κ'	tan δ
25	9.01	.00051
100	9.14	.00055
200	9.30	.00074
300	9.46	.00108
400	9.53	.00149
500	9.79	.00192
600	9.95	.00237
700	10.13	.00288
750	10.22	.00320
800	10.31	.00367
850	10.41	.0051
892	10.50	.010
3.89 - 3.61 GHz		
8.5 GHz		
25	8.98	.00058



Alberox Corp. A-962
96.2% Al_2O_3



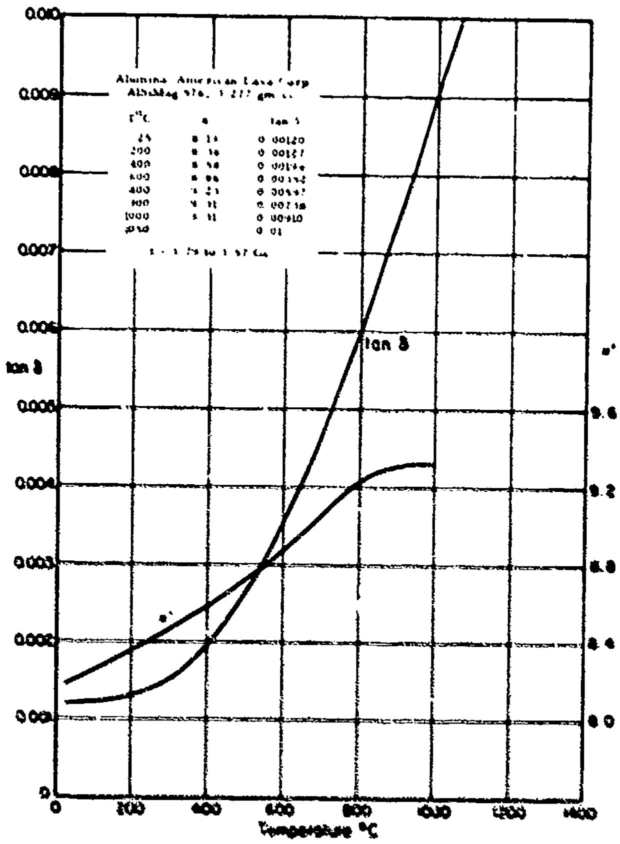
Alberox Corp. A-935
93.5% Al_2O_3
Density 3.623 g/cm^3

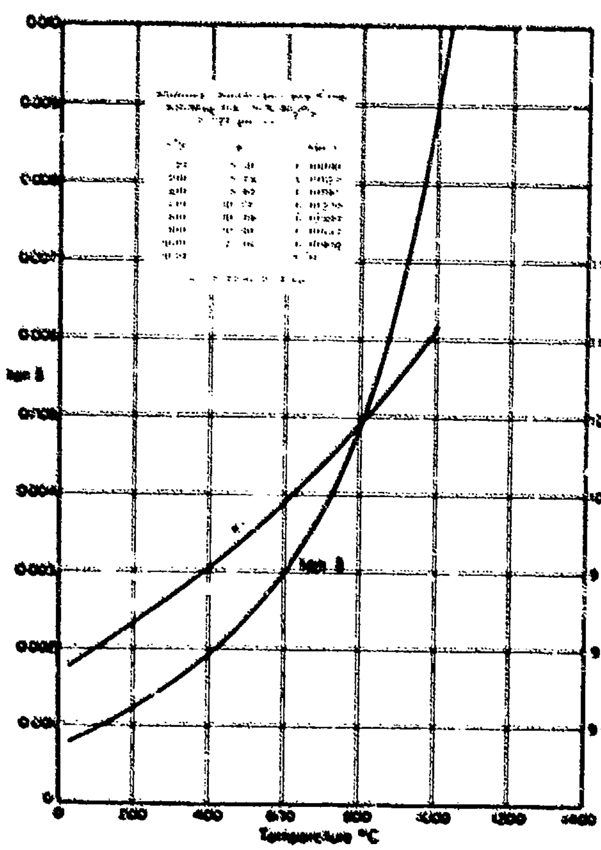
8.52 GHz

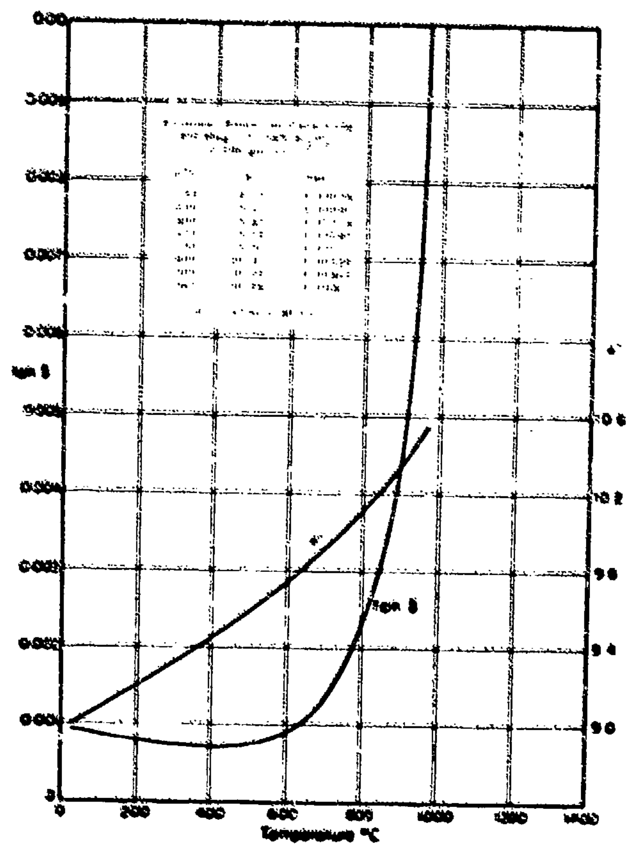
T^oC	κ	tan δ
25	8.65	.00155
100	8.73	.00208
200	8.84	.00305
300	8.95	.00423
400	9.06	.0057
500	9.18	.0081
540	9.24	.010

Alumina (cont.)

American Lava







Alumina, high-purity — Armour Research Foundation

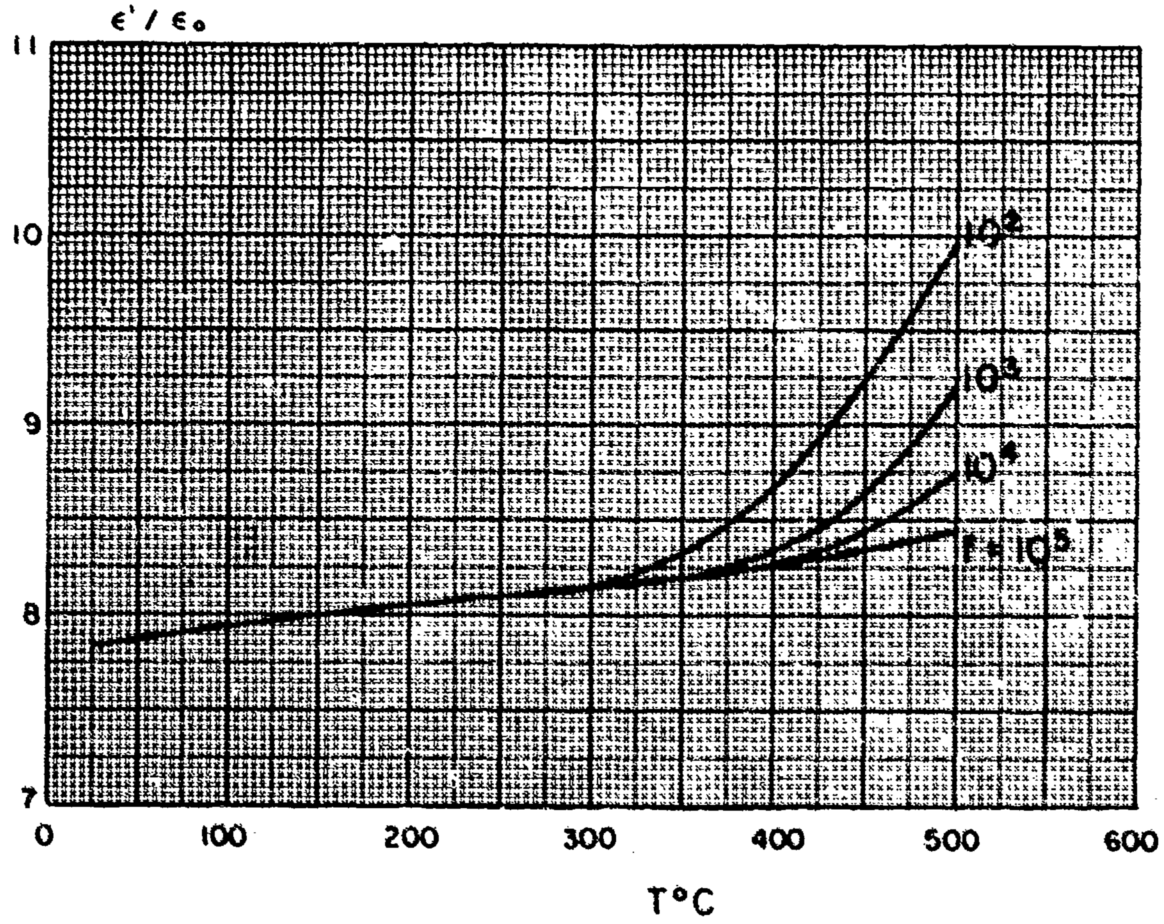
From Alcoa 99.99% Al with HF, fired air 1820°C

Spectrographic analysis: concentration of elements in parts per million:

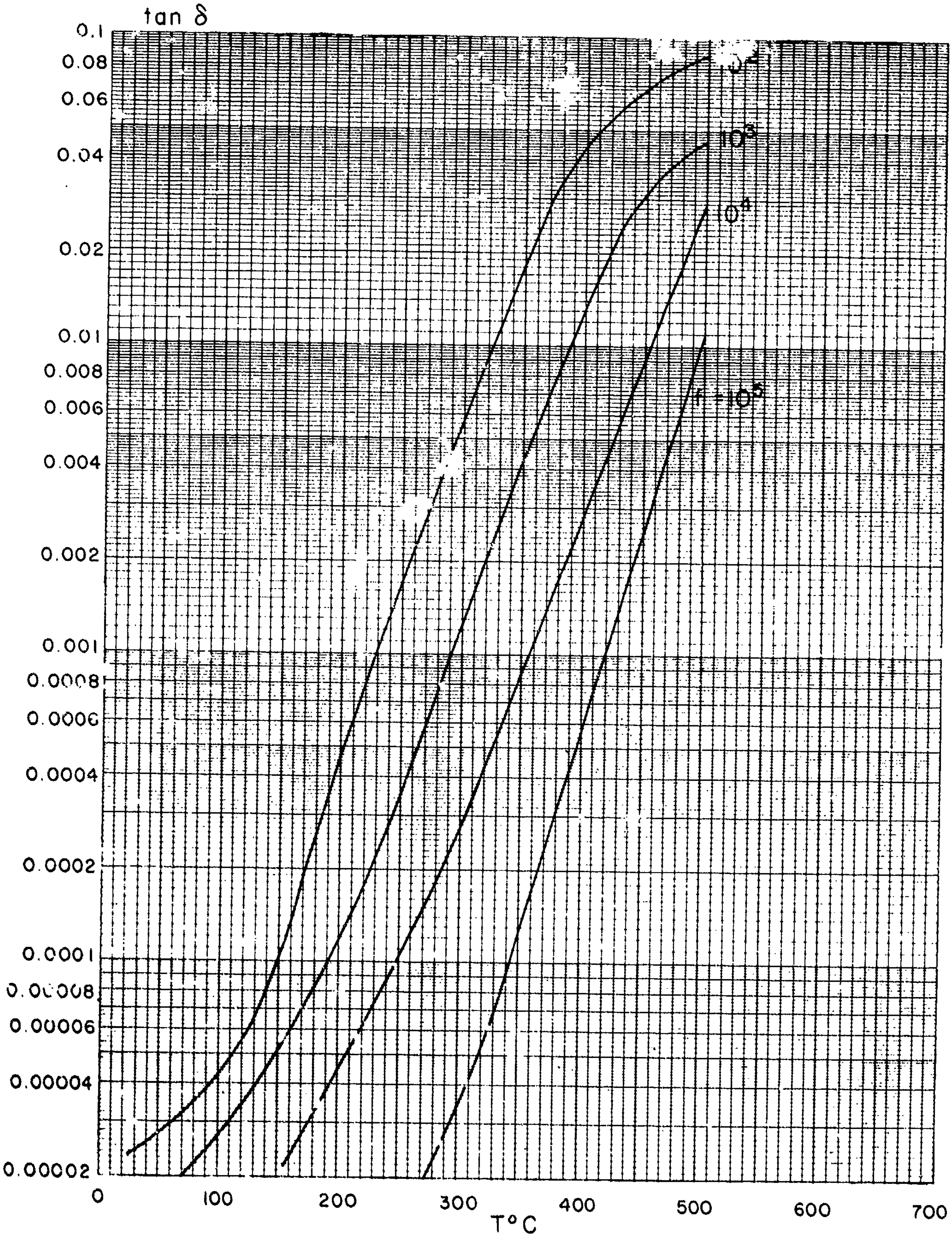
Si	Mg	Fe	Ca	Cu
111	58	38	3	5

Density 3.32 g/cm^3

Fired silver electrodes



Density 3.32


tan δ
0.1
0.08
0.06
0.04
0.02
0.01
0.008
0.006
0.004
0.002
0.001
0.0008
0.0006
0.0004
0.0002
0.0001
0.00008
0.00006
0.00004
0.00002
0
100
200
300
400
500
600
700
T°C
10^3
10^4
$f = 10^5$

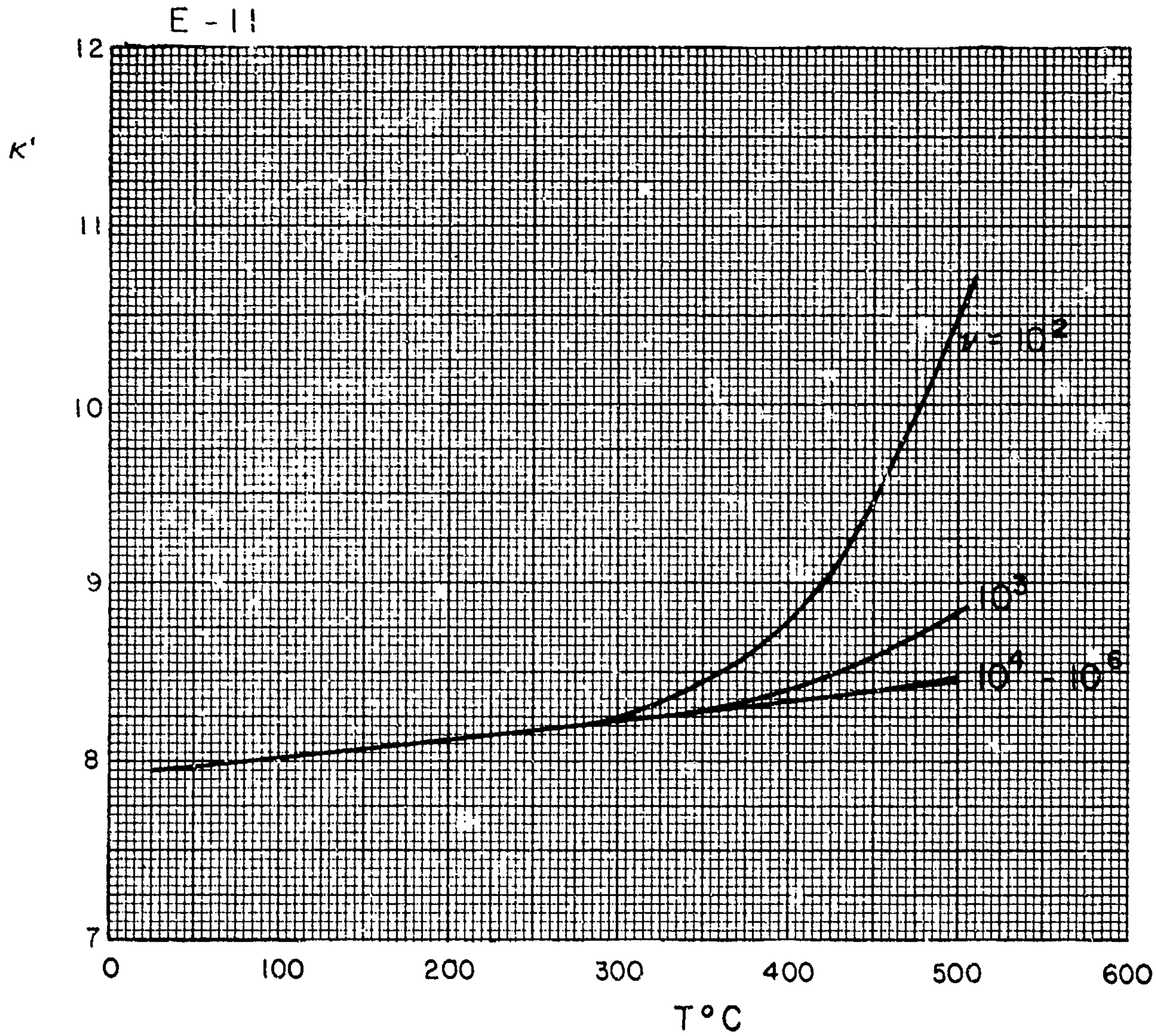
Alumina, high-purity Armour Research Foundation

From Reynolds 99.999% Al with HF, fired air 1840°C

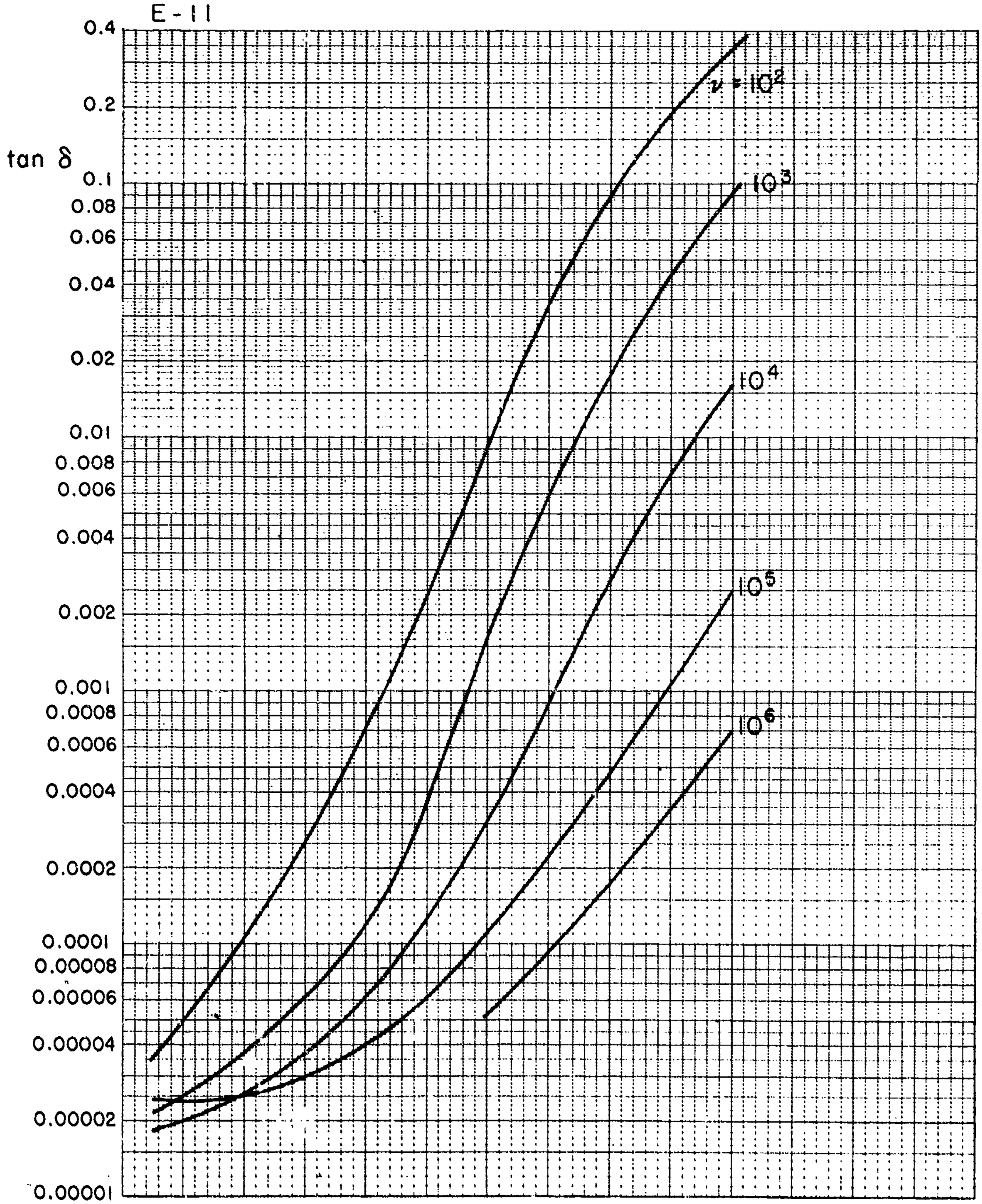
Spectrographic analysis: concentration of elements in parts per million:

Si	Mg	Fe	Ca	Ni	Cr	Cu
60	30	60	15	5	4	3

Density 3.23 g/cm^3



ν, frequency in Hz


E-11
tan δ
0.4
0.2
0.1
0.08
0.06
0.04
0.02
0.01
0.008
0.006
0.004
0.002
0.001
0.0008
0.0006
0.0004
0.0002
0.0001
0.00008
0.00006
0.00004
0.00002
0.00001
ν = 10²
10³
10⁴
10⁵
10⁶

Alumina oxide with added silicic acid   Armour Research Foundation

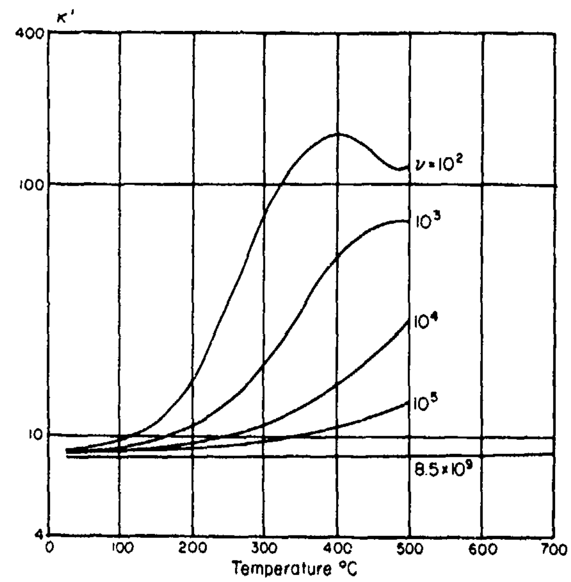
Fired air 1890°C

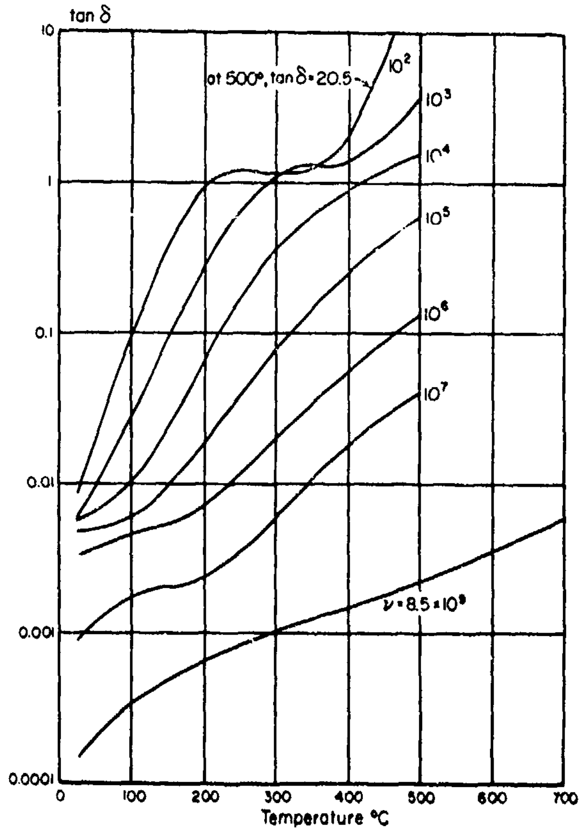
850 ppm Si, 550 ppm Na

Fired silver electrodes

Density 3.49 g/cm^3

E-20

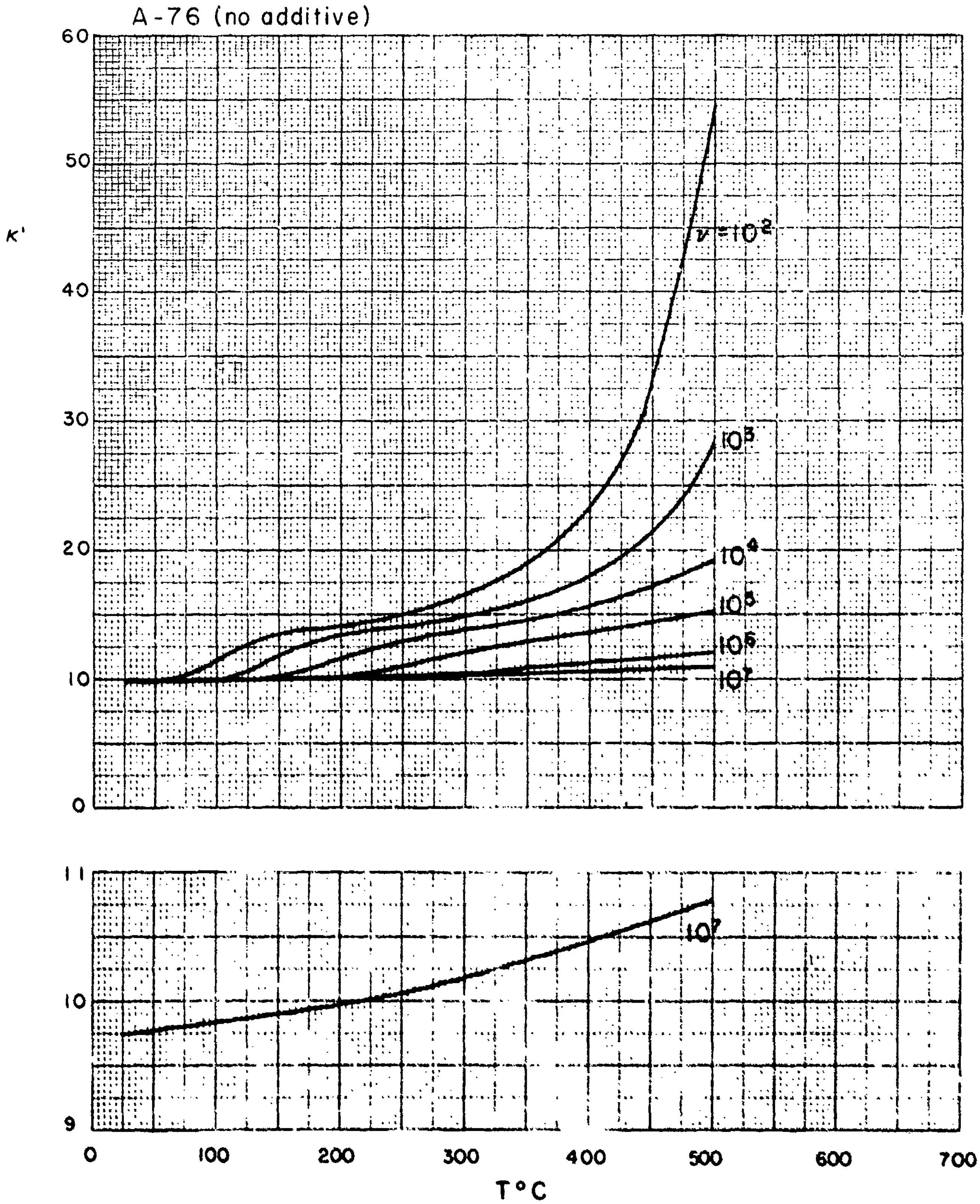




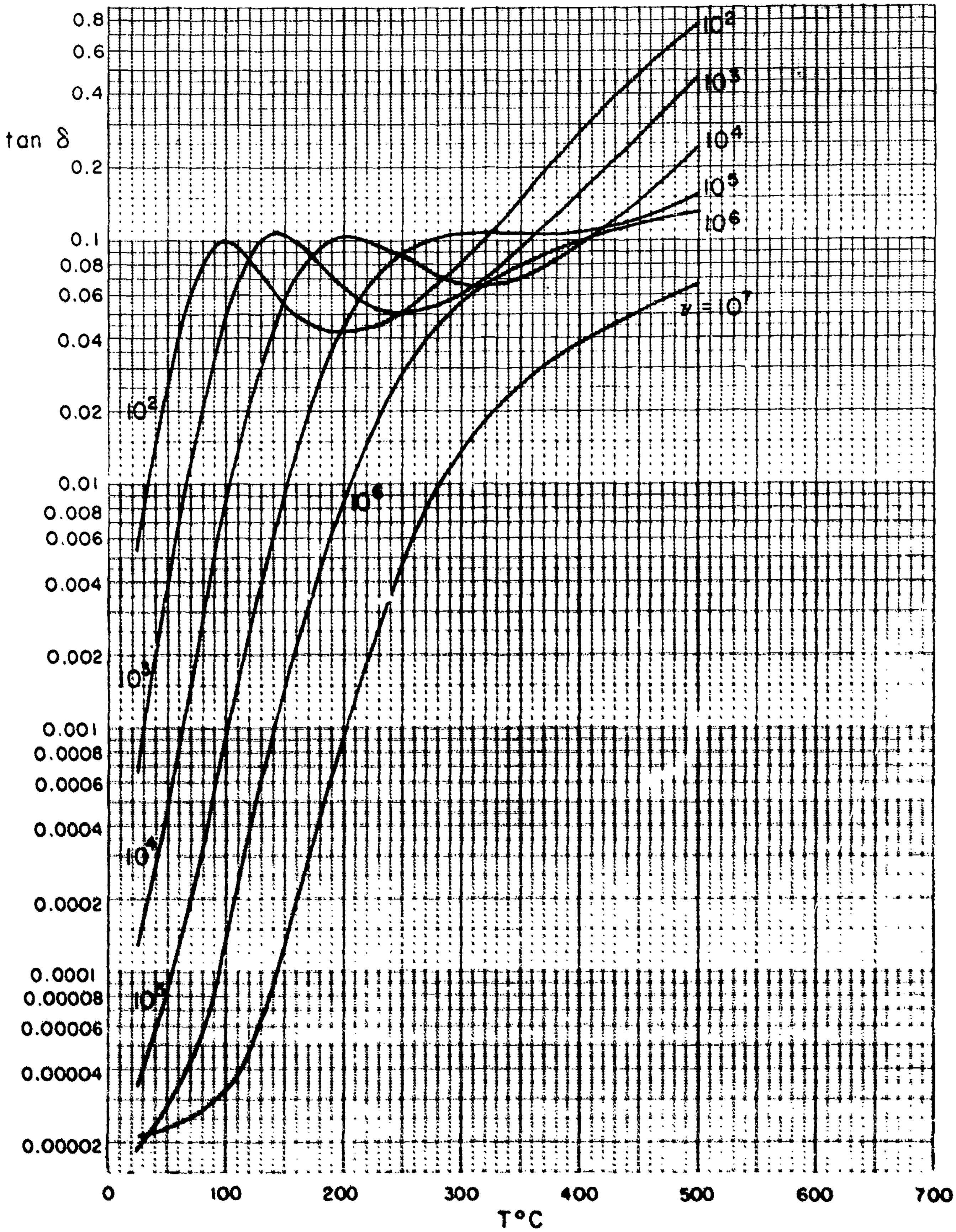
Alumina, high purity, hot-pressed in C

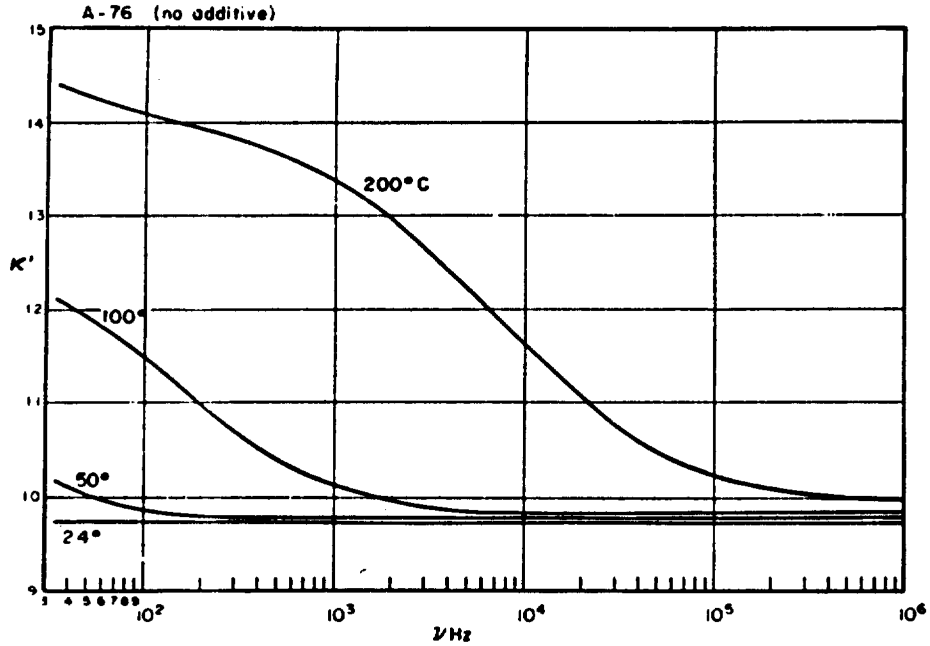
Density 3.84 g/cm^3

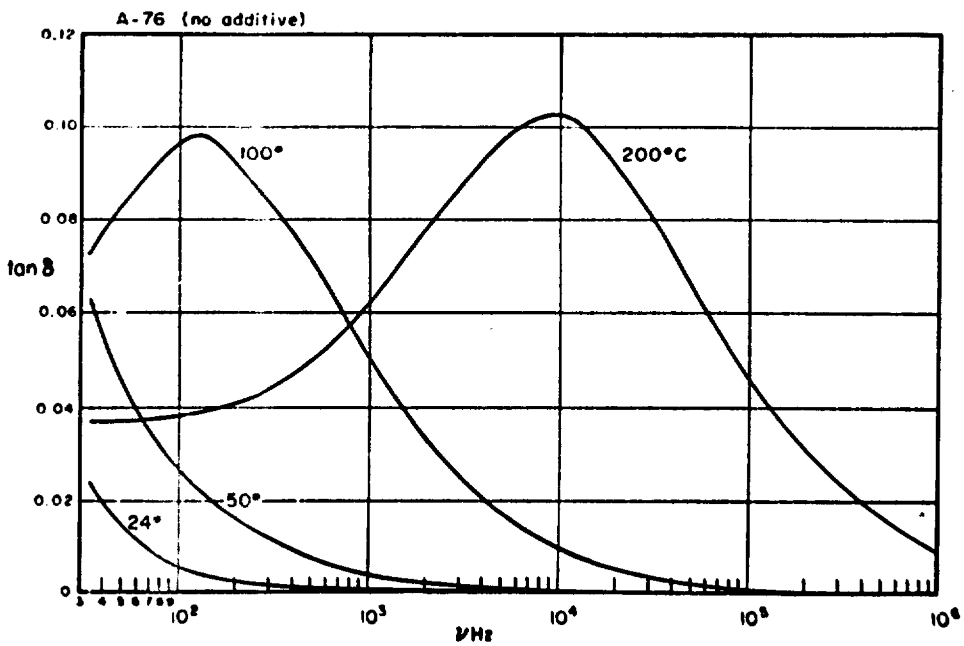
Armour Research Foundation

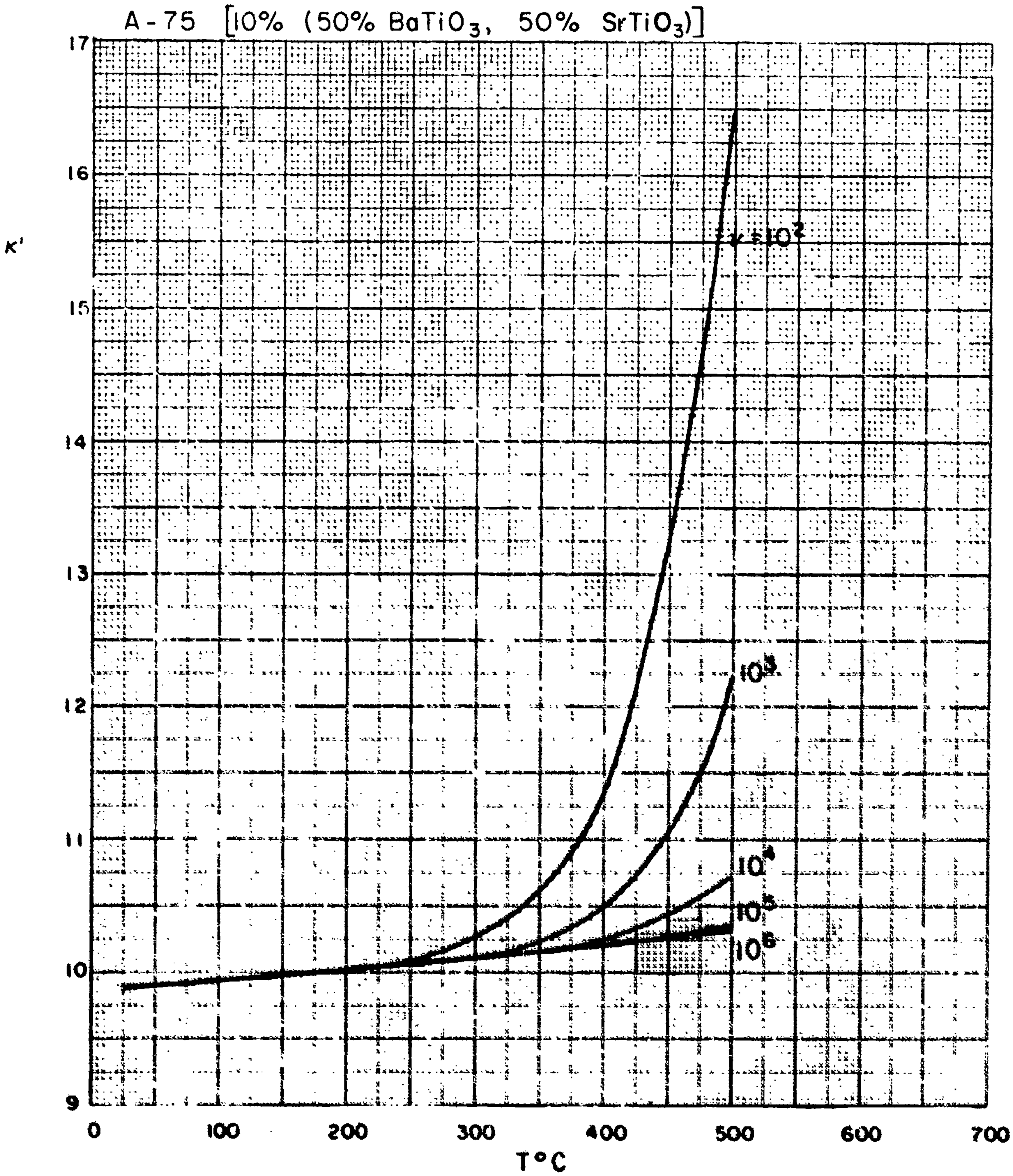


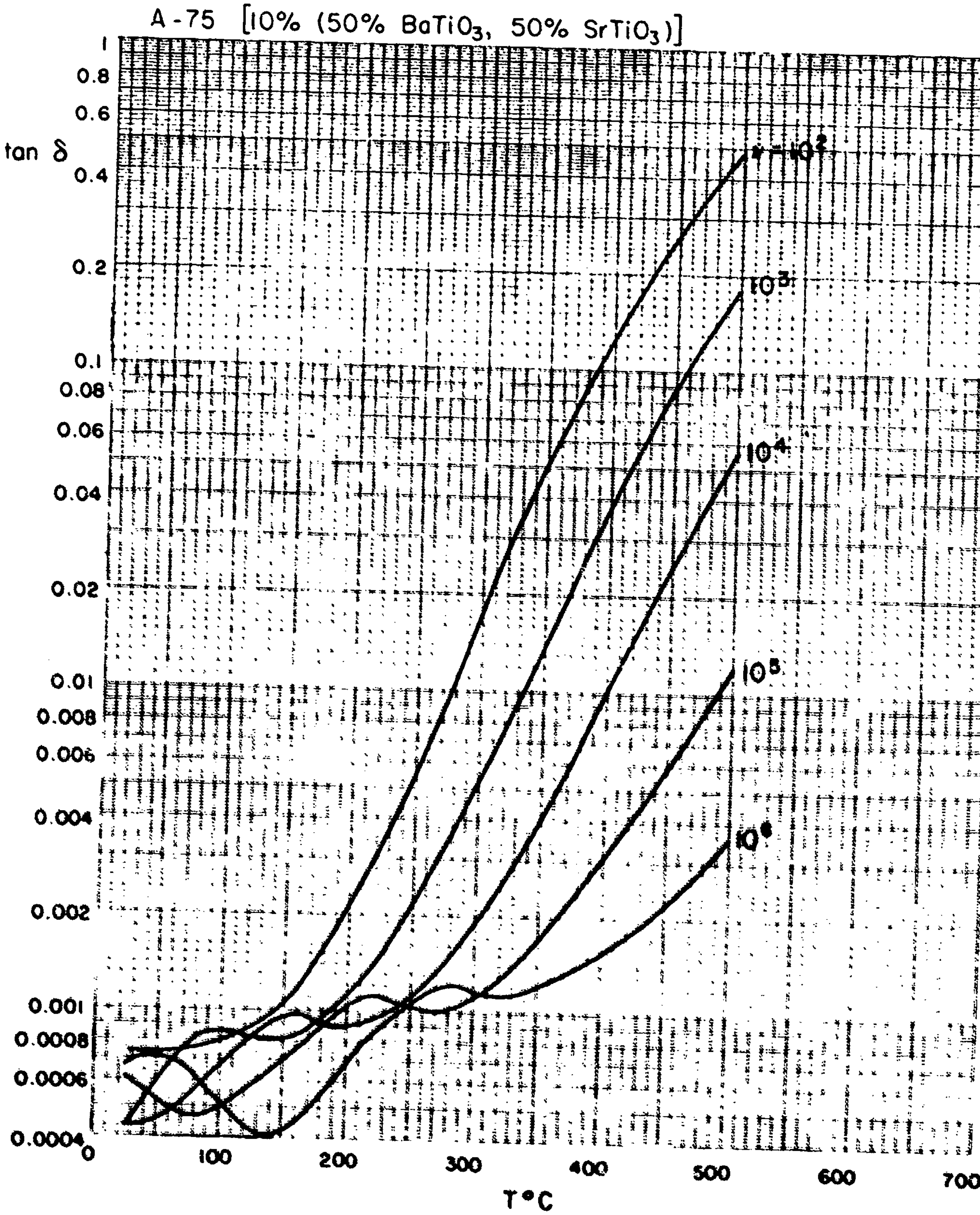
A-76 (no additive)

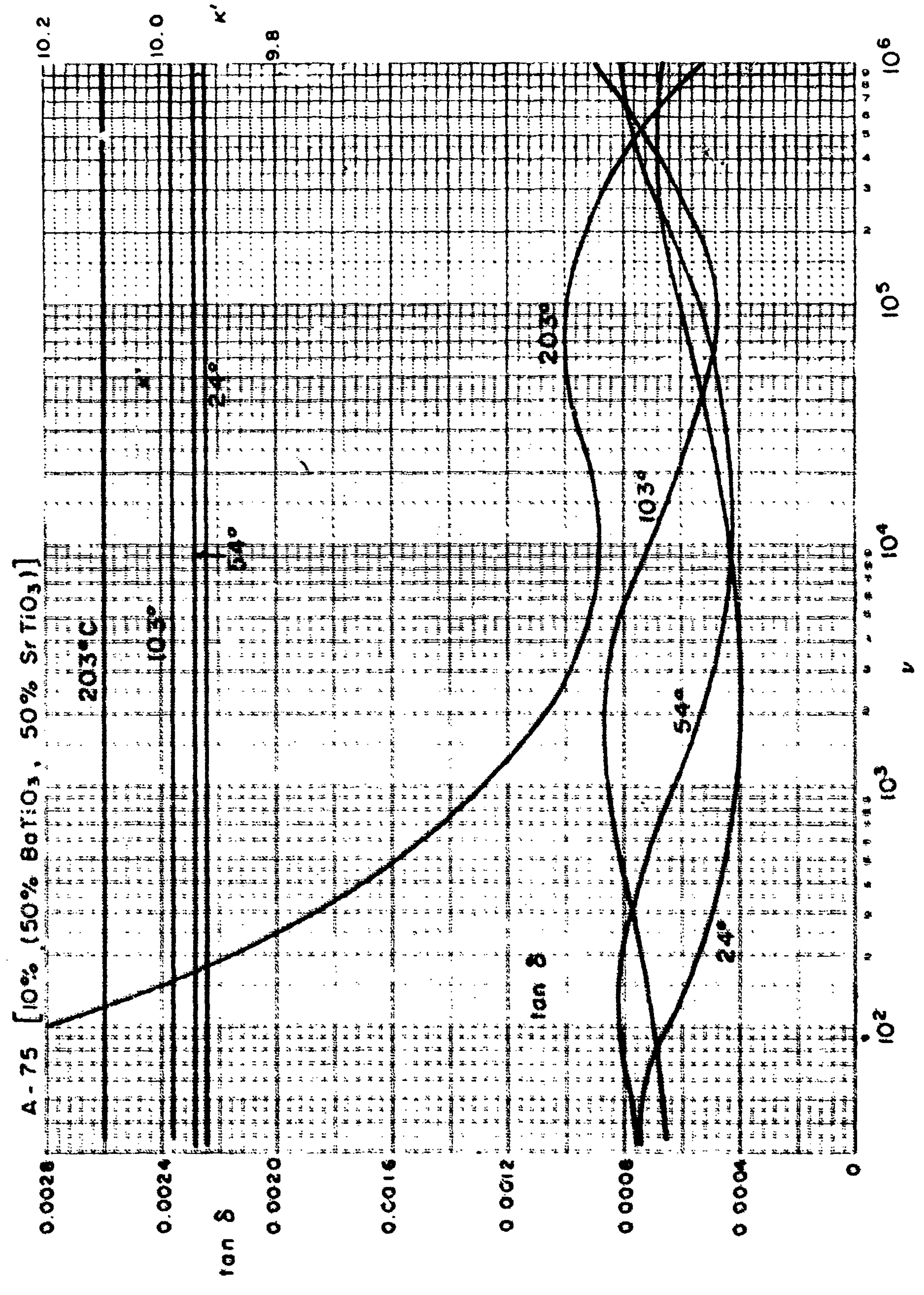



A-76 (no additive)
200°C
100°
50°
24°
K'
15
14
13
12
11
10
9
3 4 5 6 7 8 9
10^2
10^3
10^4
10^5
10^6
ν Hz

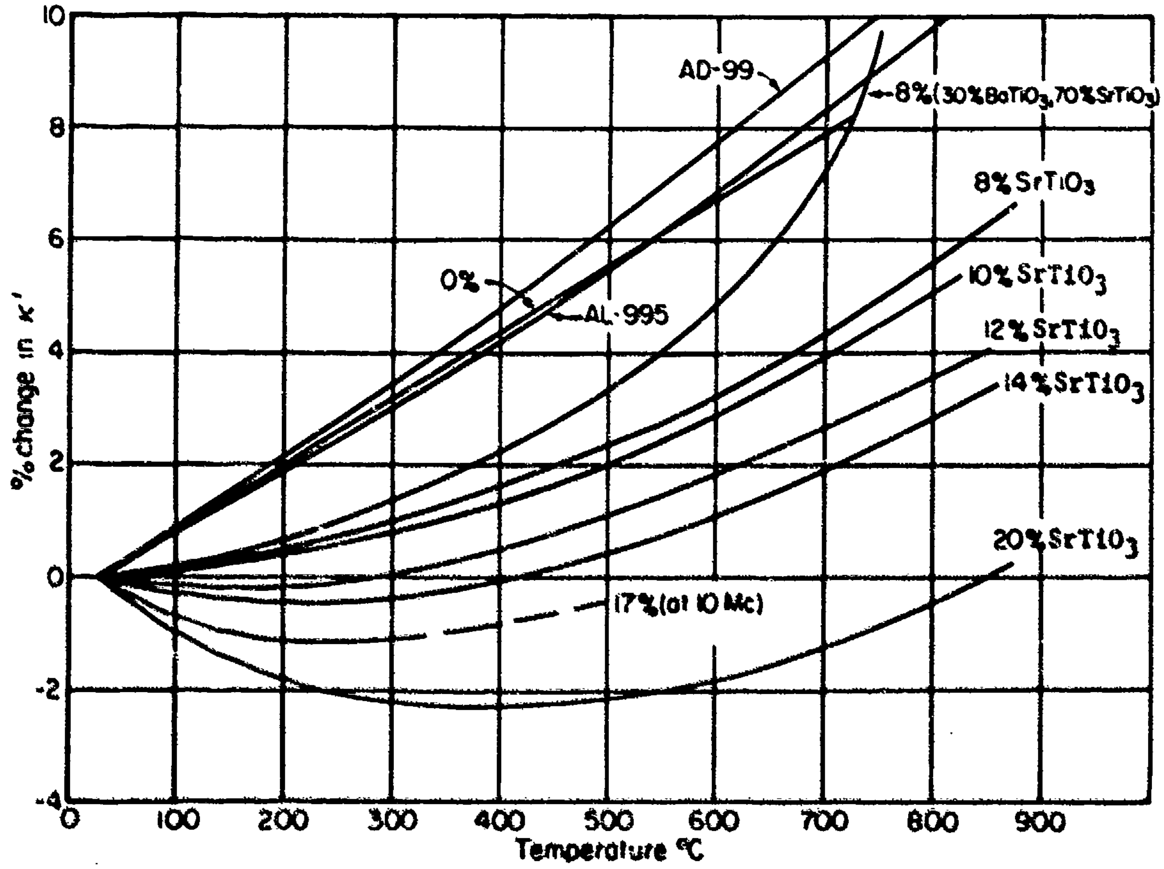

A-76 (no additive)
100°
200°C
50°
24°
tan δ
0.12
0.10
0.08
0.06
0.04
0.02
0
3 4 5 6 7 8 9
10^2
10^3
10^4
10^5
10^6
ν Hz


A-75 [10% (50% $BaTiO_3$, 50% $SrTiO_3$)]
κ'
17
16
15
14
13
12
11
10
9
0
100
200
300
400
500
600
700
T°C
ν = 10²
10³
10⁴
10⁵
10⁶

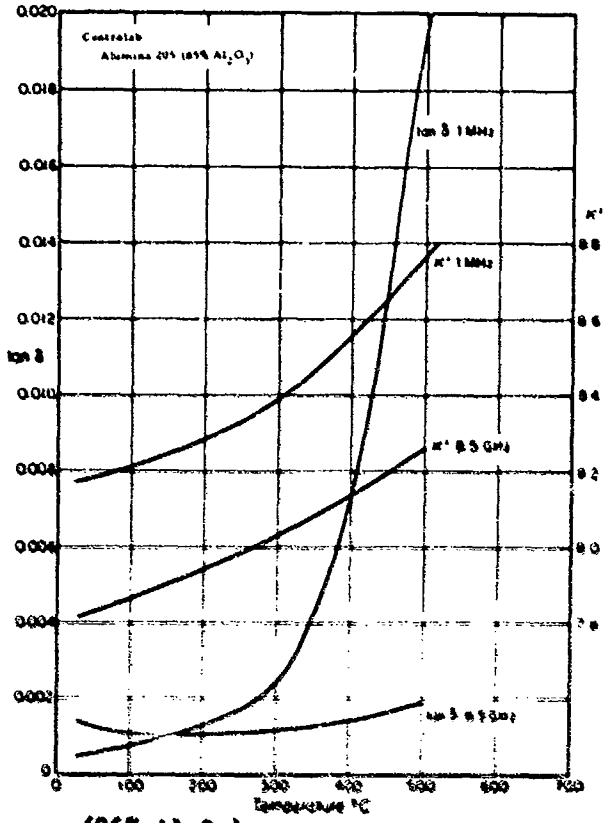

A-75 [10% (50% $BaTiO_3$, 50% $SrTiO_3$)]
tan δ
1
0.8
0.6
0.4
0.2
0.1
0.08
0.06
0.04
0.02
0.01
0.008
0.006
0.004
0.002
0.001
0.0008
0.0006
0.0004
0
100
200
300
400
500
600
700
T°C
$f = 10^2$
10^3
10^4
10^5
10^6

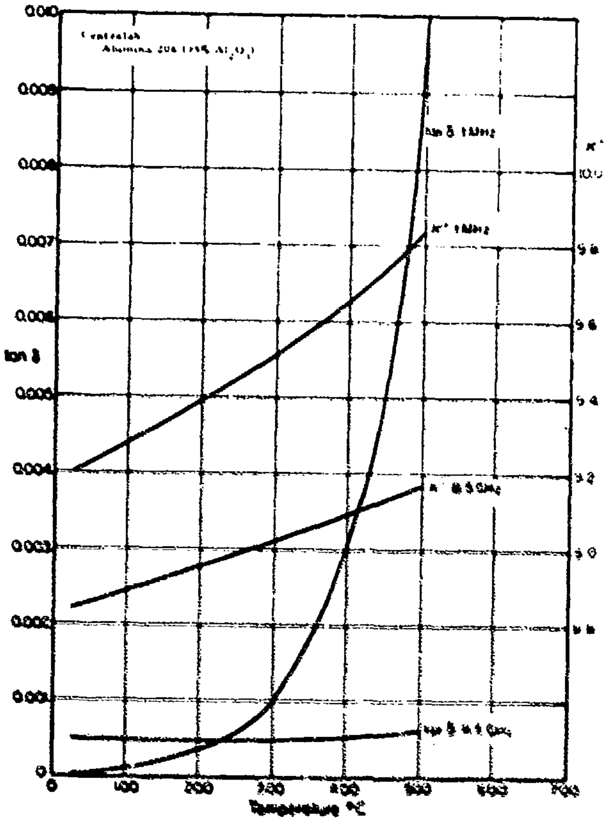

A - 75 [10% (50% BaTiO₃, 50% SrTiO₃)]
203°C
103°
24°
54°
κ'
tan δ
ν
10.2
10.0
9.8
0.0028
0.0024
0.0020
0.0016
0.0012
0.0008
0.0004
0
10²
10³
10⁴
10⁵
10⁶

Change in dielectric constant
with temperature for various
aluminas at ca. 4000 MHz

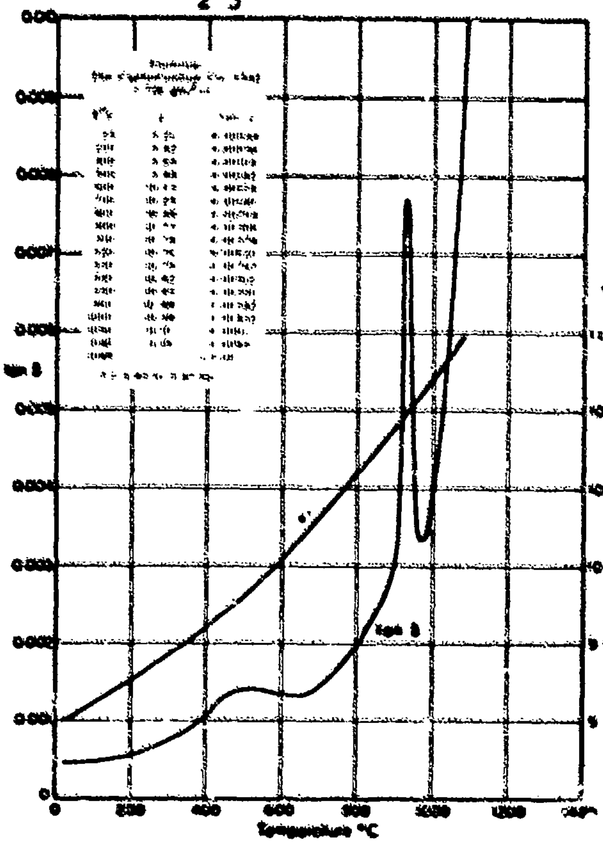


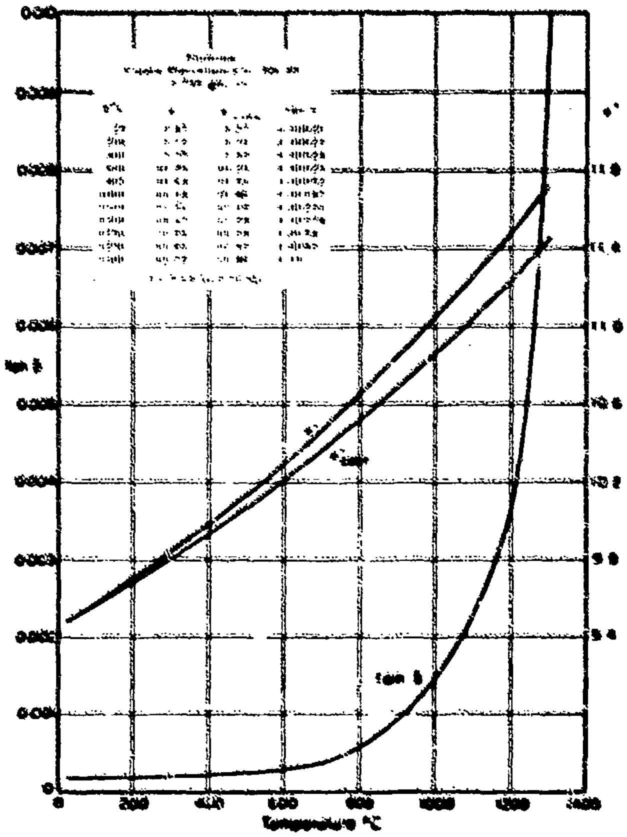
Alumina (cont.)



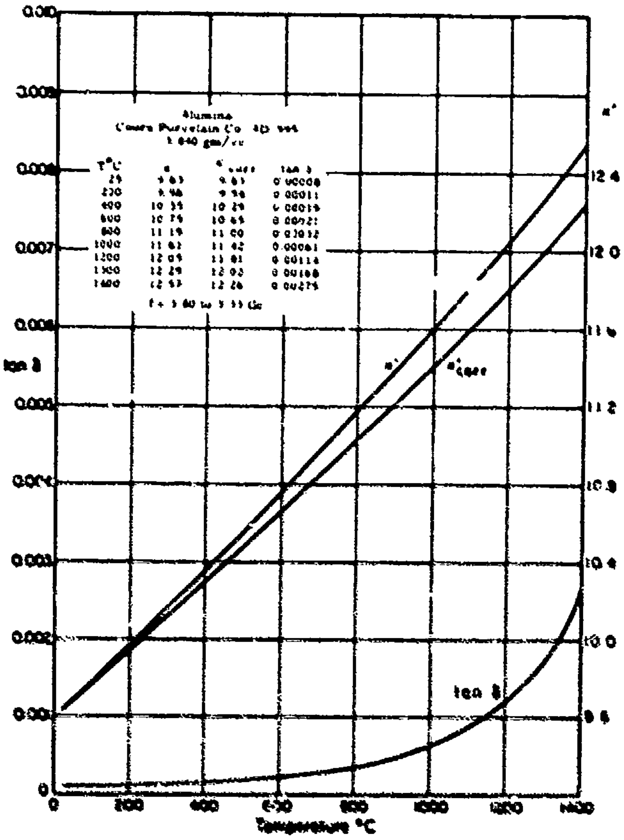


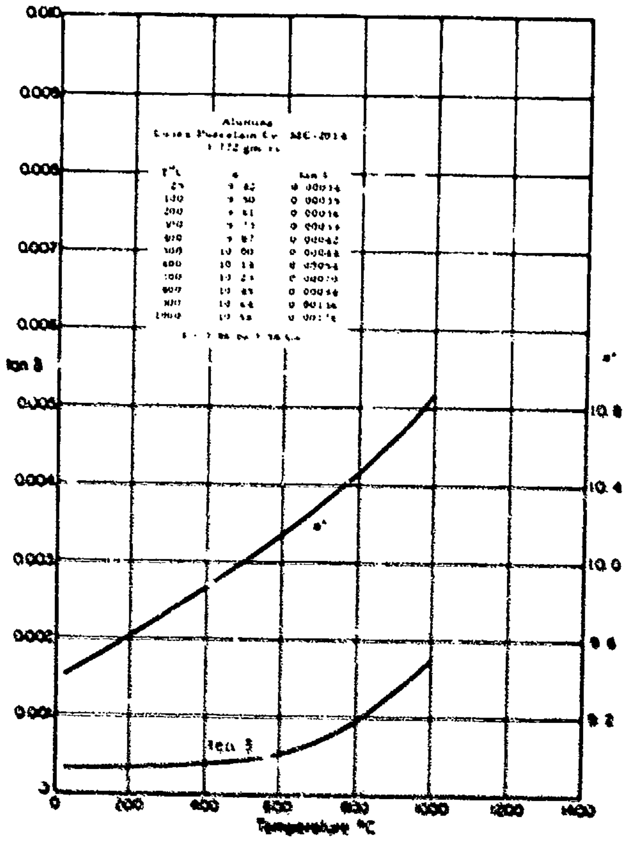
(96% Al_2O_3)

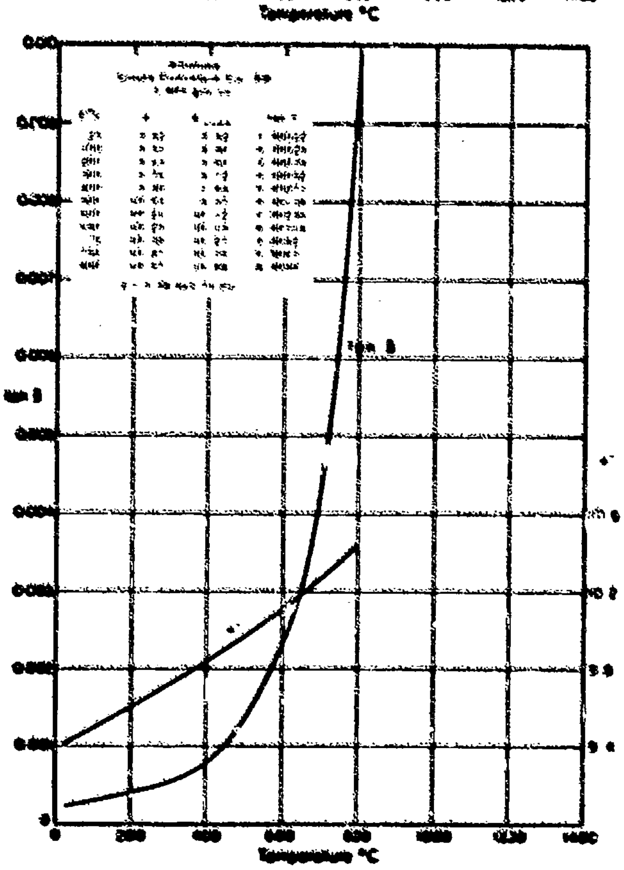


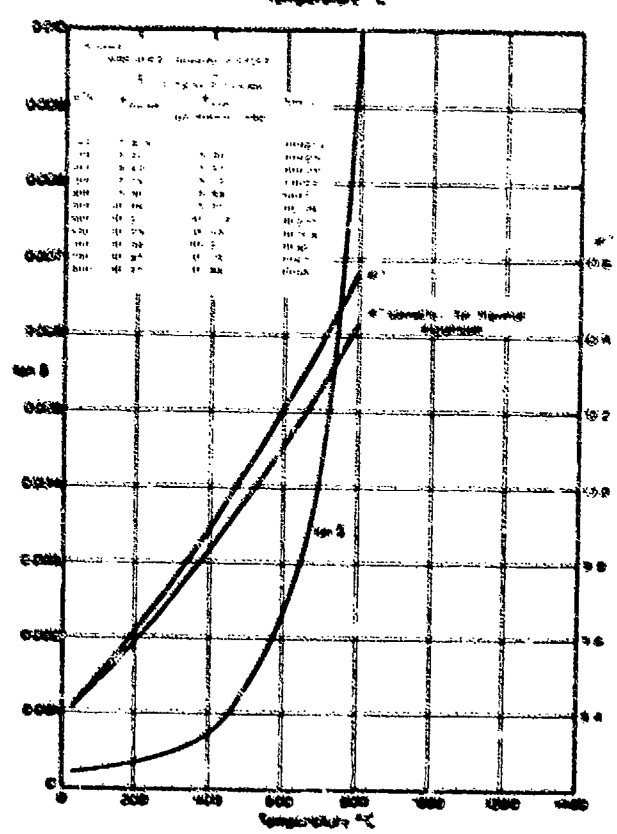


Alumina (cont.)



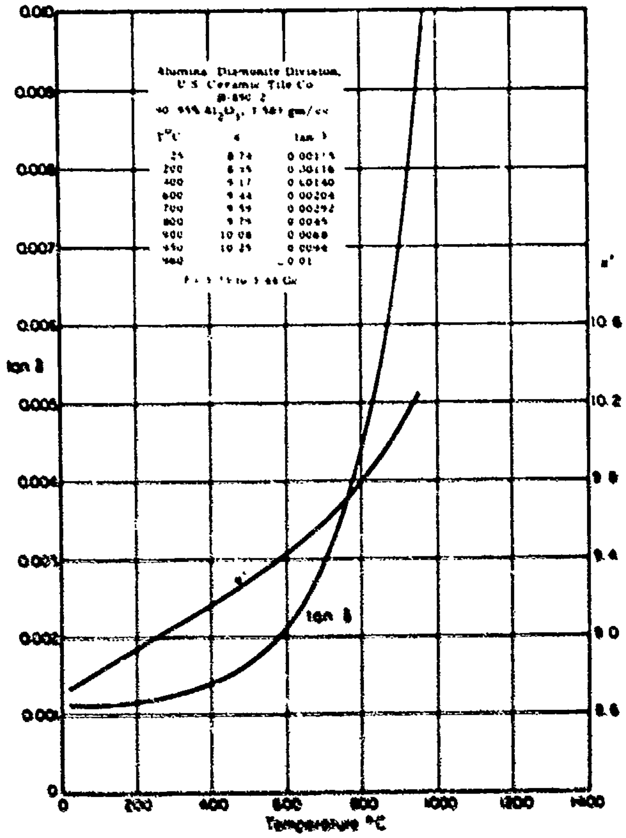


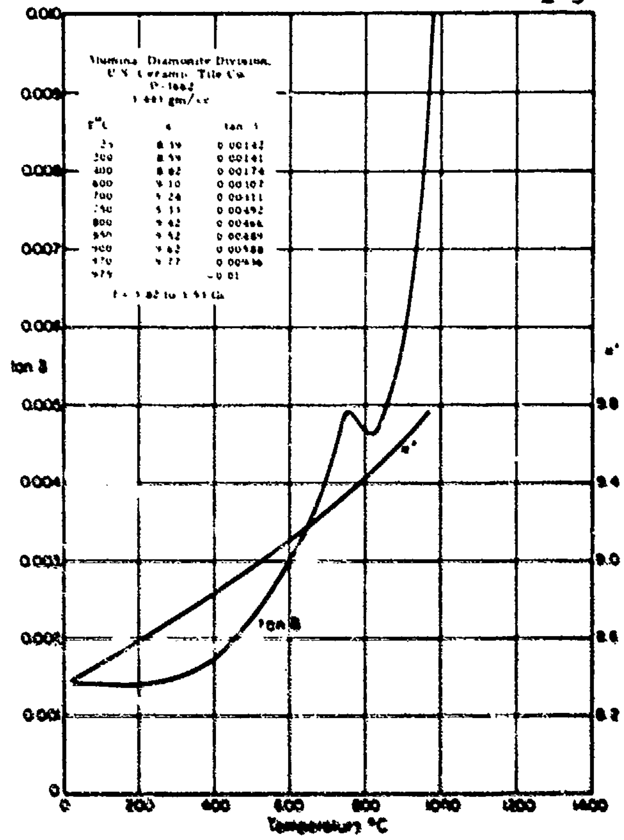


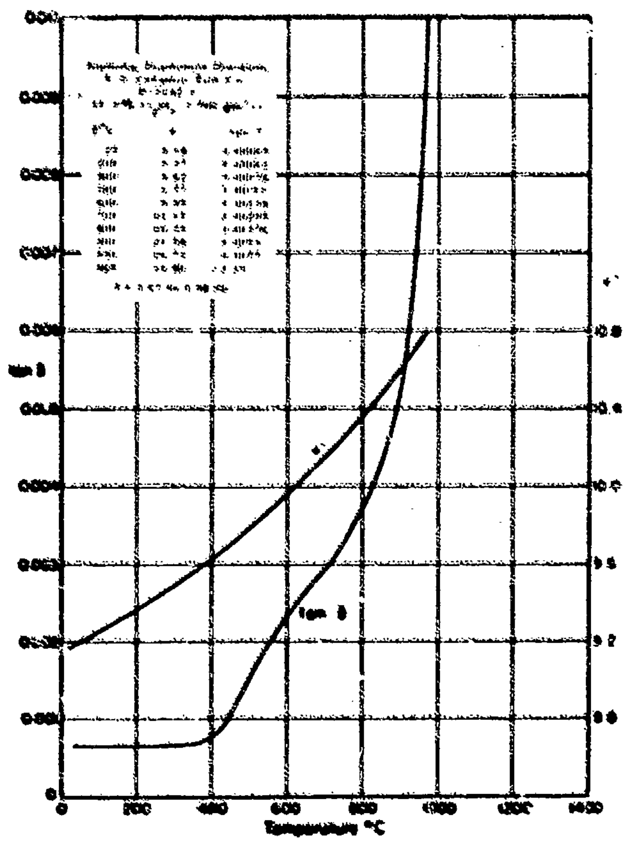


Alumina (cont.)

(85%-90% Al_2O_3)







<u>Frenchtown 7225</u>

8.52 GHz, 25°C

κ' = 8.8 ± 0.05

tan δ = 0.0013 ± 0.0002

on two samples

Aluminum oxide, multicrystalline

AT-100 (near 100% Al_2O_3, fine grained)

Density, g/cm^3: (10^2 to 10^8 Hz) - 3.956

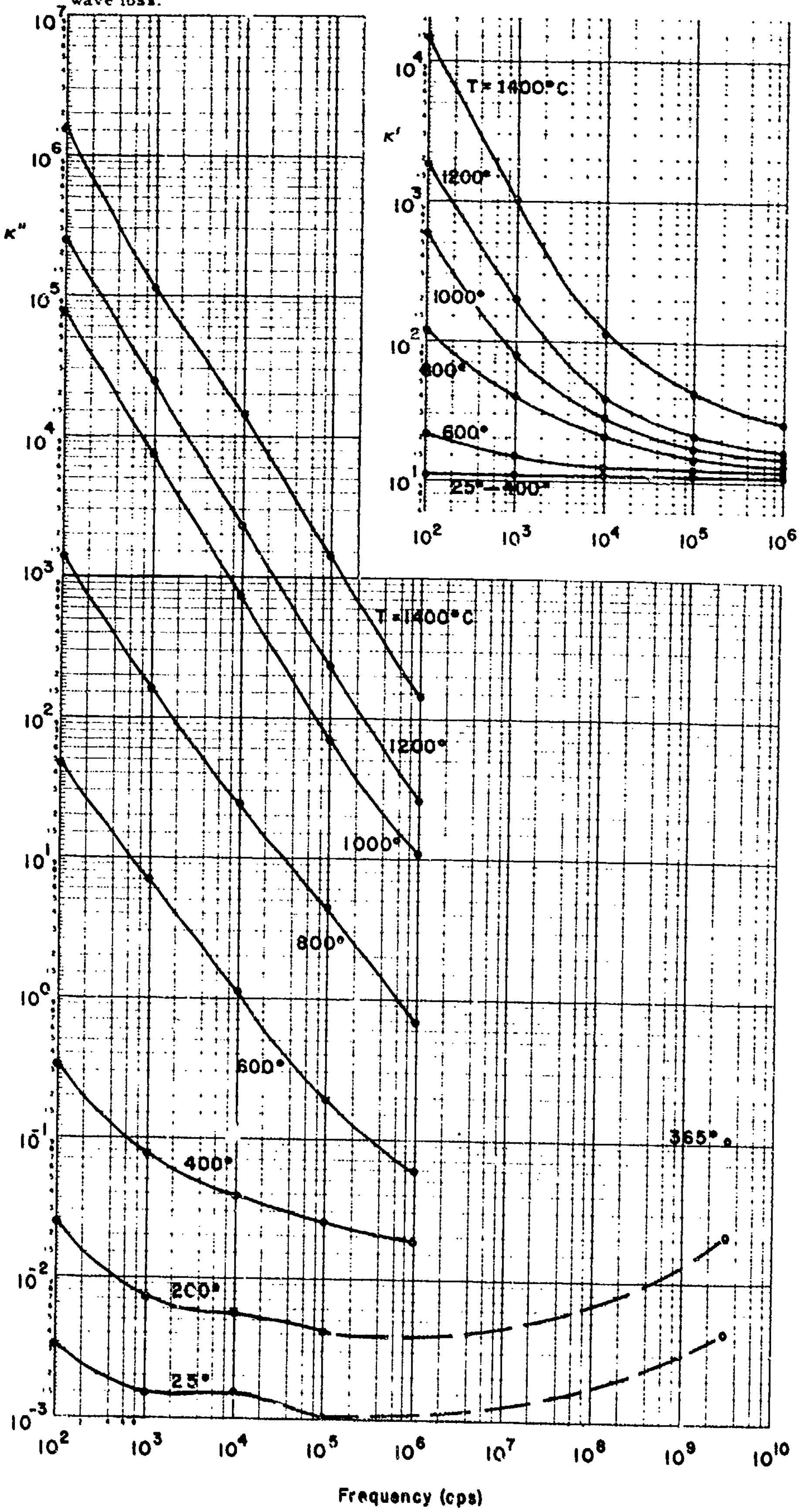
(4; 8 GHz) - 3.955

General Electric Company
Electronic Components Division

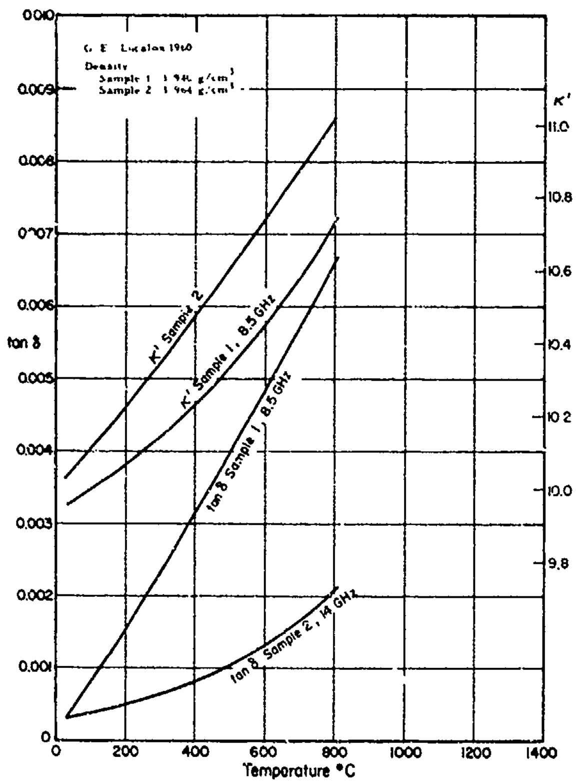
Frequency in Hz

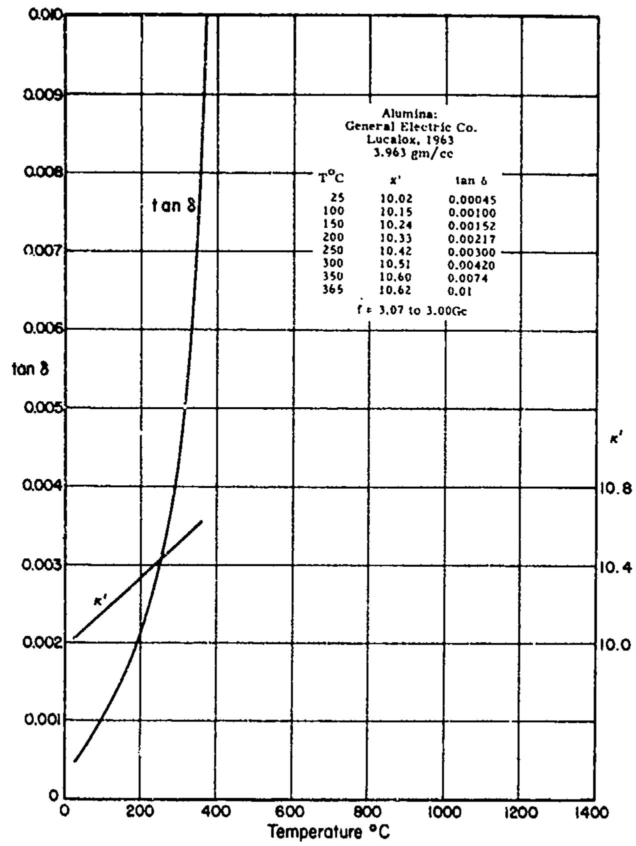
T°C		10^2	10^3	10^4	10^5	10^6	10^7	8.5×10^9
25	κ	9.98	9.98	9.98	9.98	9.98	9.98	9.96
	10^6 tanδ	7	<1	<1	<1	<1.5	<7	48
100	κ	10.09	10.09	10.09	10.09	10.09	10.09	
	10^6 tanδ	52	6	<1	<1	<1.5	<7	
200	κ	10.21	10.21	10.21	10.21	10.21	10.21	
	10^6 tanδ	603	128	45	20	10	<7	
300	κ	10.42	10.37	10.355	10.35	10.35	10.35	
	10^4 tanδ	61.3	16.3	5.27	2.28	.62	.12	
400	κ	10.84	10.68	10.57	10.46	10.44	10.44	
	tanδ	0307	.0133	.00407	.00103	.00034	.00006	
500	κ	12.60	11.28	10.86	10.71	10.63	10.62	
	tanδ	.289	.069	.0237	.0044	.00082	.0002	

Al_2O_3 ceramic, General Electric Co. "Lucalox." Curves show data on samples bought in 1963. Tabulation of data on earlier samples, 1962, show appreciably lower microwave loss.



Alumina (cont.)





A-919 (97% Al_2O_3, magnesia-free) General Electric Co.

Density, g/cm^3: (10^2 to 10^8 Hz) - 3.747
($8.5x10^9$ Hz) - 3.750

		Frequency in Hz						
T°C		10^2	10^3	10^4	10^5	10^6	10^7	$8.5x10^9$
25	κ	10.33	9.95	9.62	9.45	9.38	9.37	9.35
	tan δ	.0240	.0251	.0206	.0082	.00139	.00030	
100	κ	10.29	9.88	9.60	9.51	9.49	9.49	.00069
	tan δ	.0316	.0252	.0123	.00303	.00048	.00025	
200	κ	9.74	9.62	9.60	9.59	9.59	9.59	
	tan δ	.0210	.0046	.00089	.00021	.00006	<.0001	
300	κ	10.32	9.89	9.79	9.78	9.77	9.77	
	tan δ	.0760	.0237	.00475	.00097	.00033	.00010	
400	κ	14.38	11.13	10.18	9.96	9.90	9.89	
	tan δ	1.65	.295	.0590	.0106	.00195	.00063	
500	κ	16.56	13.67	11.44	10.37	10.08	10.03	
	tan δ		6.83	.866	.122	.0203	.0035	

Aluminum oxide, multicrystalline

A-923 (97% Al_2O_3) General Electric Company

Density, g/cm^3: (10^2 to 10^8 Hz) - 3.740

(8.5×10^9 Hz) - 3.740

Frequency in Hz

T°C		10^2	10^3	10^4	10^5	10^6	10^7	8.5×10^9
25	κ	10.26	10.23	10.10	9.61	9.28	9.27	9.24
	tan δ	.00227	.00432	.0173	.0357	.00952	.00165	.00067
100	κ	10.33	10.30	10.19	9.72	9.40	9.39	
	tan δ	.00330	.00352	.0178	.0320	.0118	.00157	
200	κ	10.18	9.73	9.55	9.53	9.50	9.50	
	tan δ	.0349	.0238	.0073	.00200	.0089	.00040	
300	κ	10.38	9.84	9.74	9.65	9.64	9.64	
	tan δ	.0678	.0232	.0074	.00313	.00167	.00112	
400	κ	12.50	10.48	9.97	9.82	9.80	9.79	
	tan δ	.205	.082	.0228	.00735	.0035	.0017	
500	κ	16.72	13.93	10.98	10.08	9.95	9.91	
	tan δ	8.03	1.20	.240	.0444	.00976	.0037	

A-923 (97% Al_2O)

Density 3.740 g/cm^3

Freq. 3.74 - 3.37 GHz

T°C	κ	tan δ	T°C	κ	tan δ
25	9.31	.00039	705	10.42	.00215
99	9.41	.00042	800	10.63	.00265
184	9.58	.00053	903	10.86	.0033
281	9.72	.00070	973	10.98	.0040
356	9.84	.00090	1025	11.17	.0045
430	9.96	.00112	1050	11.22	.0050
562	10.17	.00160	1109	11.38	.0060
			1132	11.41	.010

A-976 (near 100%)

$T^{o}C$		Frequency in Hz 10^2	10^3	10^4	10^5	10^6	10^7	8.5×10^9
25	κ	9.90	9.90	9.90	9.90	9.90	9.90	9.81
	10^6 tanδ	70	34	20	10	<10	<10	66
100	κ	10.01	10.01	10.00	10.00	10.00	10.00	
	10^5 tanδ	15	7	3	1.5	<1	<1	
200	κ	10.14	10.12	10.11	10.11	10.11	10.1	
	10^5 tanδ	66	23	8	6	3	<1	
300	κ	10.32	10.29	10.26	10.26	10.26	10.26	
	10^4 tanδ	25	11	3.8	1.1	.4	.2	
400	κ	10.65	10.50	10.43	10.42	10.41	10.41	
	10^4 tanδ	395	102	27.8	8.7	2.9	1.0	
500		11.30	10.81	10.65	10.59	10.58	10.56	
	10^3 tan	461	118	22.4	4.59	1.97	1.1	

Density of disk - 3.919; density of cylinder - 3.917

Aluminum oxide, multicrystalline

A-1000 (99.8% Al_2O_3, fine grained) General Electric Company

Density, g/cm^3: (10^2 to 10^8 Hz) - 3.900

(8.5×10^9) - 3.896

Frequency in Hz

T°C		10^2	10^3	10^4	10^5	10^6	10^7	8.5×10^9
25	κ	10.08	10.08	10.07	10.04	9.98	9.96	9.77
	tan δ	.00048	.00048	.00135	.00354	.00664	.00612	.00258
100	κ	10.20	10.16	10.15	10.15	10.15	10.15	
	tan δ	.00184	.00077	.00037	.00058	.00208	.0061	
200	κ	10.39	10.36	10.33	10.33	10.31	10.29	
	tan δ	.00344	.00198	.00101	.00045	.00051	.00170	
300	κ	10.65	10.55	10.51	10.47	10.45	10.44	
	tan δ	.0193	.0059	.00226	.00079	.00049	.00065	
400	κ	11.86	10.89	10.68	10.63	10.60	10.58	
	tan δ	.213	.0461	.00936	.00208	.00076	.00057	
500	κ	33.3	13.98	11.28	10.83	10.80	10.76	
	tan δ	1.212	.585	.130	.0201	.00341	.00135	

Aluminum oxide, multicrystalline General Electric Company

A-1004 (94% Al_2O_3)

At 25°C: $2x10^4$ Hz, κ = 10.10, tan δ = .0426; $5x10^4$ Hz, κ = 9.76, tan δ = .0536;
$3x10^5$, κ = 9.19, tan δ = .0341.

Density, g/cm^3: (10^2 to 10^8 Hz) - 3.645
($8.5x10^9$ Hz) - 3.649

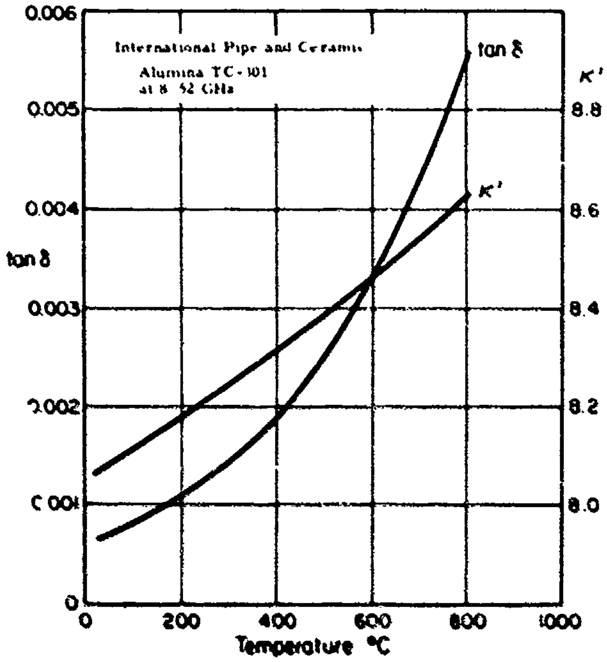
Frequency in Hz

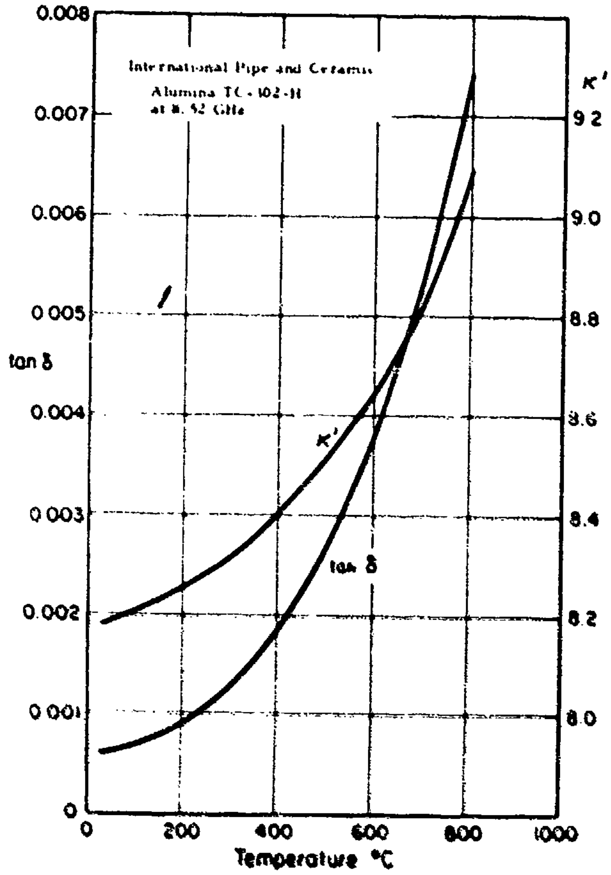
T°C		10^2	10^3	10^4	10^5	10^6	10^7	$8.5x10^9$
25	κ	10.48	10.41	10.26	9.51	9.10	9.00	9.01
	tan δ	.00226	.00716	.0319	.0534	.0142	.00228	.00125
100	κ	10.63	10.55	10.48	9.89	9.19	9.10	
	tan δ	.00355	.00555	.0208	.0505	.0271	.0515	
200	κ	10.49	9.73	9.34	9.25	9.21	9.20	
	tan δ	.0450	.0439	.0171	.0047	.00163	.00105	
300	κ	10.52	9.81	9.55	9.44	9.37	9.36	
	tan δ	.0767	.043	.0132	.0059	.0022	.0020	
400	κ	12.63	10.39	9.78	9.54	9.43	9.36	
	tan δ	.227	.0887	.033	.0136	.0072	.0040	
500	κ	19.19	12.59	10.55	10.03	9.83	9.74	
	tan δ	1.16	.452	.121	.0298	.0133	.0071	

A-1004 (94% Al_2O_3), density 3.649 g/cm^3

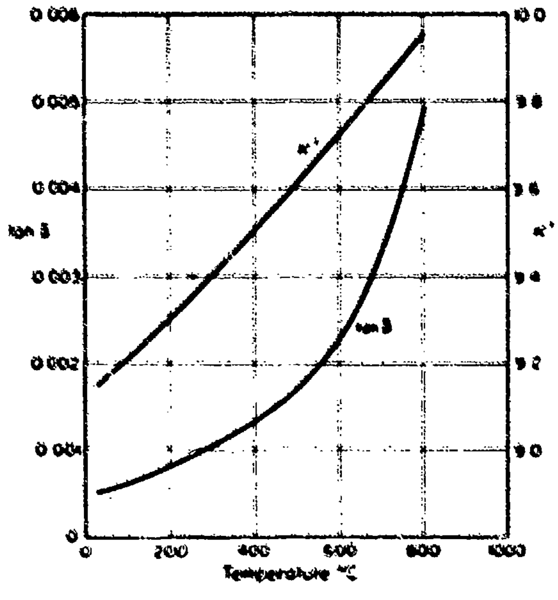
Freq. 3.80 - 3.61 GHz

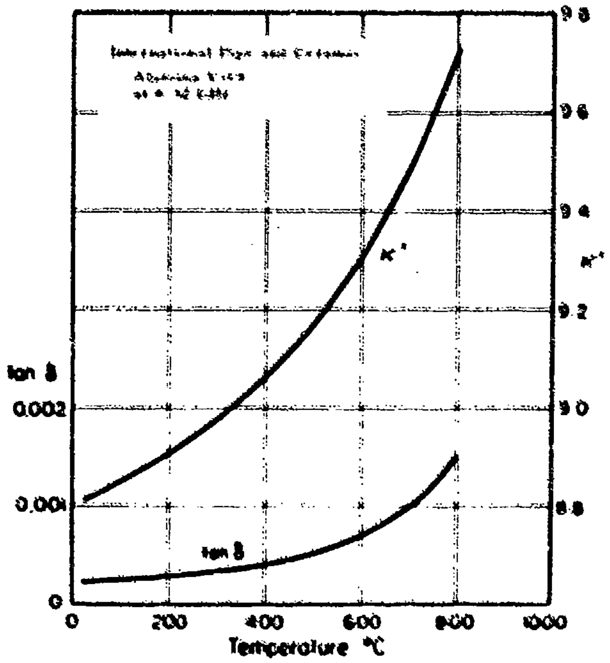
T°C	κ	tan δ
25	9.02	.00076
100	9.11	.00078
200	9.26	.00081
300	9.40	.00093
400	9.55	.00109
500	9.69	.00128
600	9.84	.00177
650	9.92	.00335
700	10.00	.0093





International Pipe and Ceramic
TC-351, at 8.52 GHz

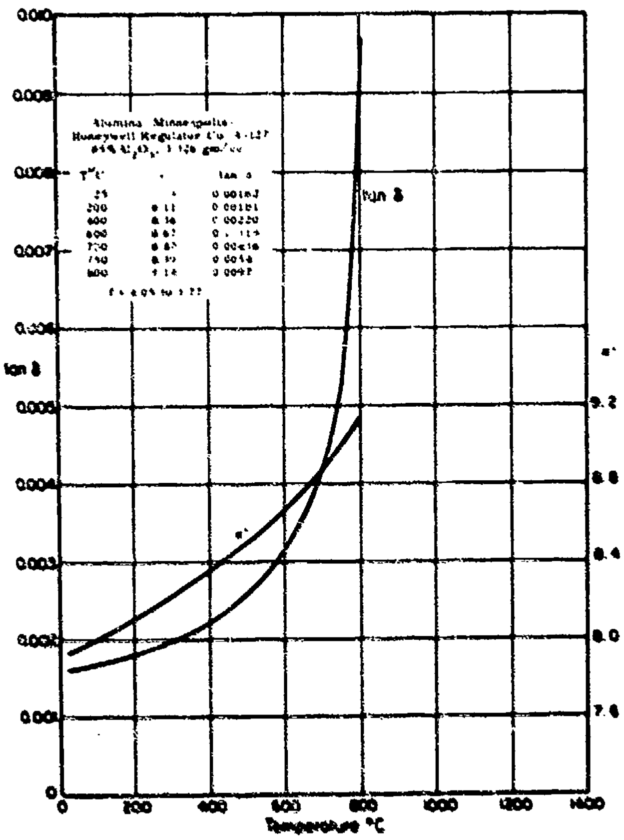


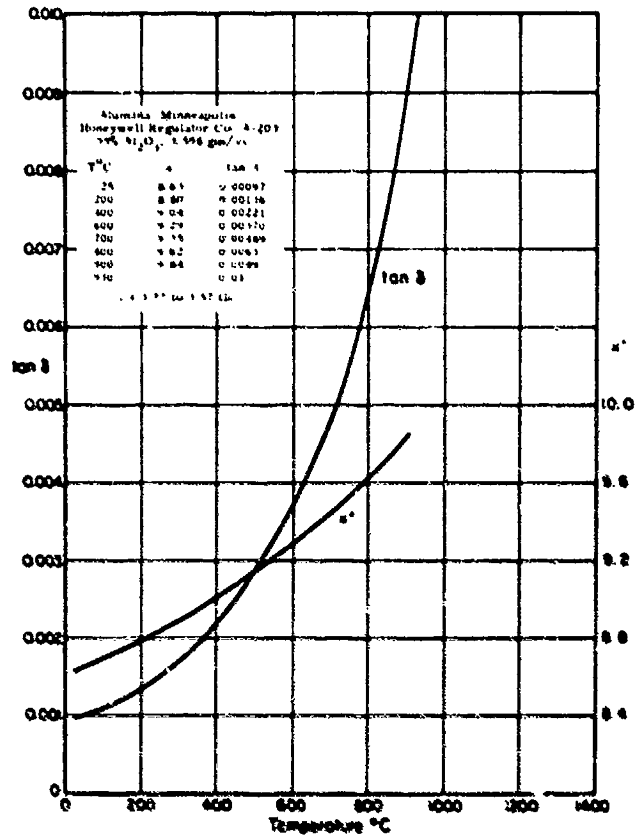


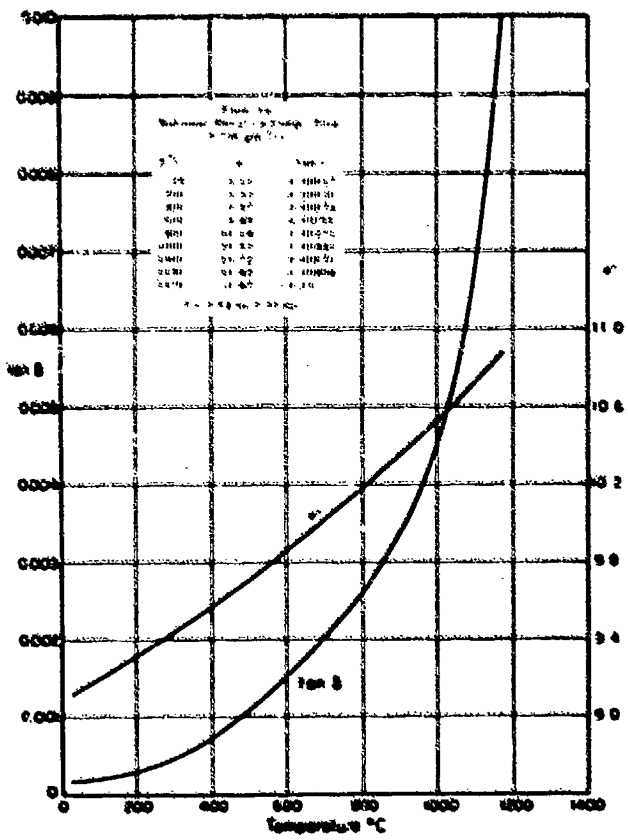
High-purity alumina at 50 GHz, 25°C
$\kappa' = 9.5$, $\tan\delta = 1 \times 10^{-5}$

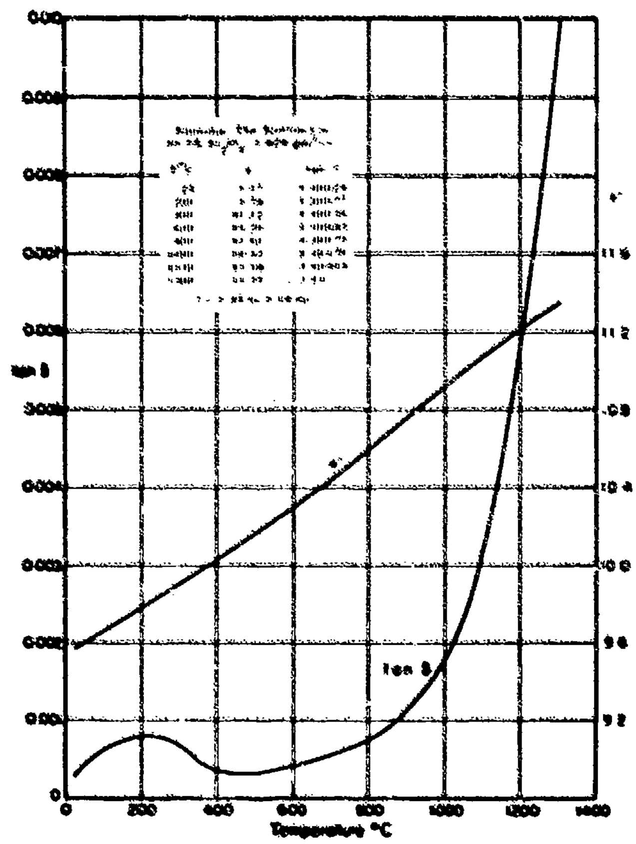
Kearfott

Alumina (cont.)



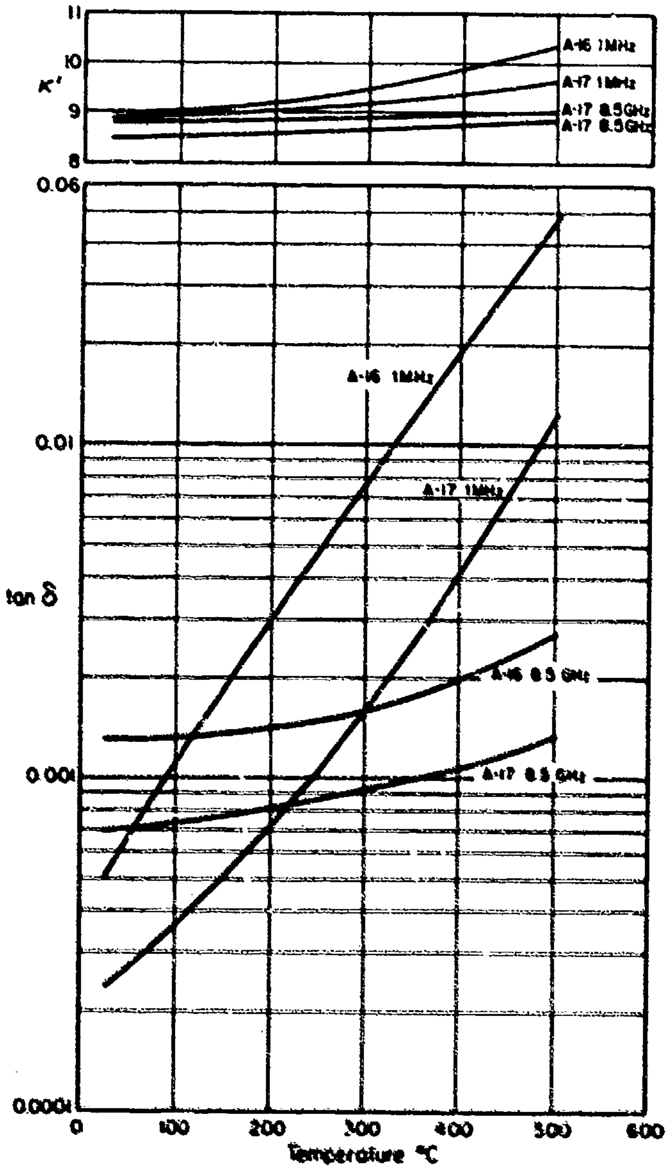




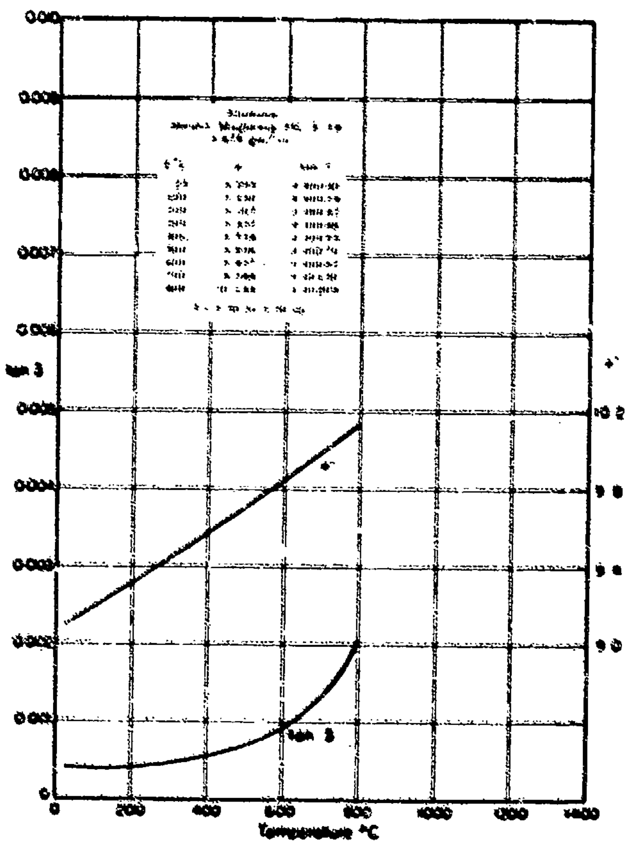


Alumina (cont.)

Aluminum oxide, multicrystal, 1959
Raytheon Company

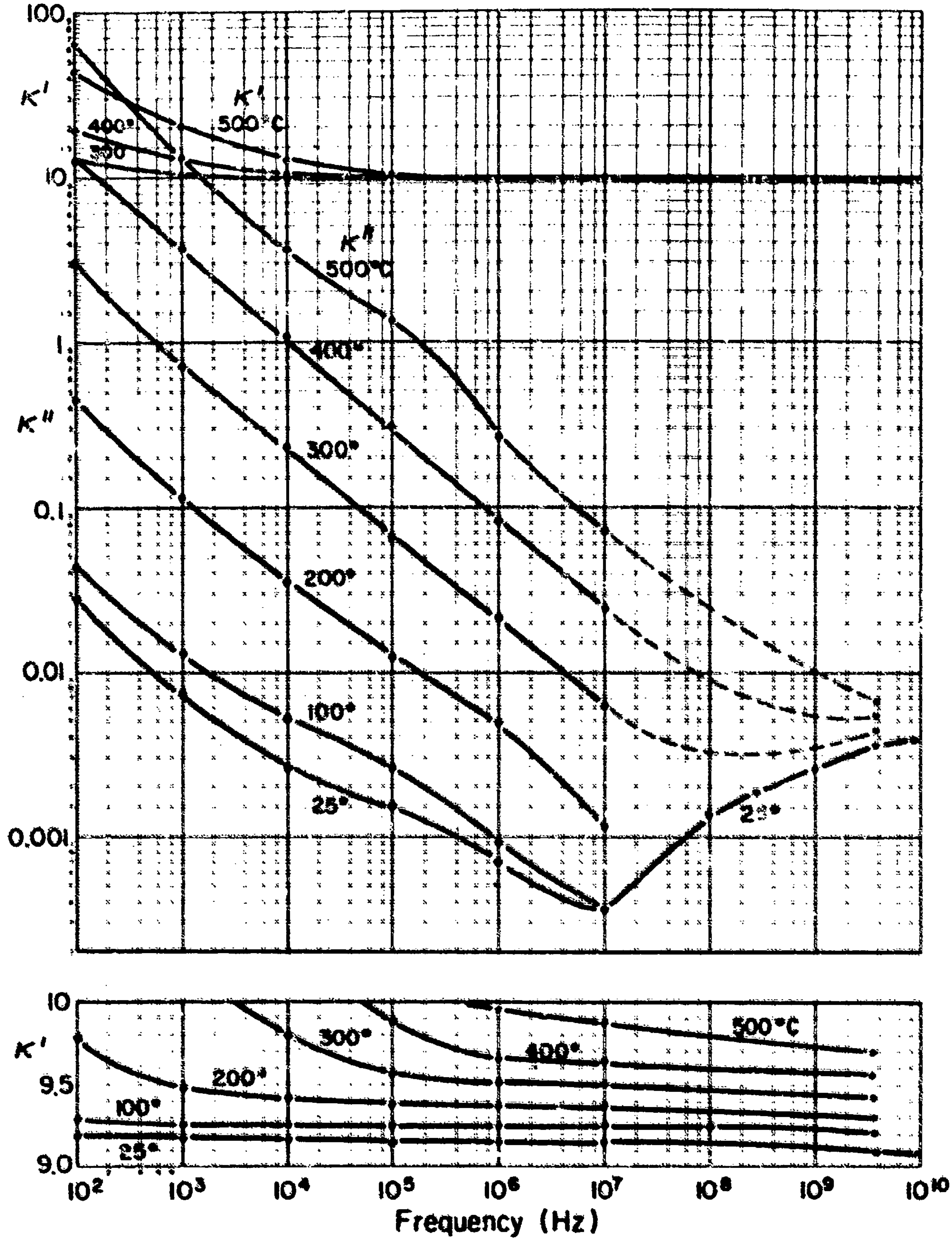


Steatit-Magnesia A.G.

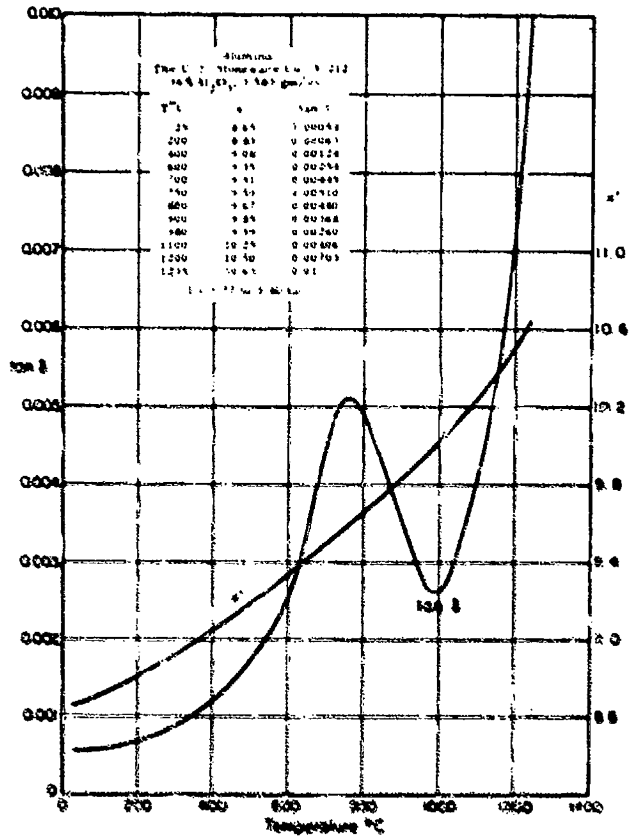


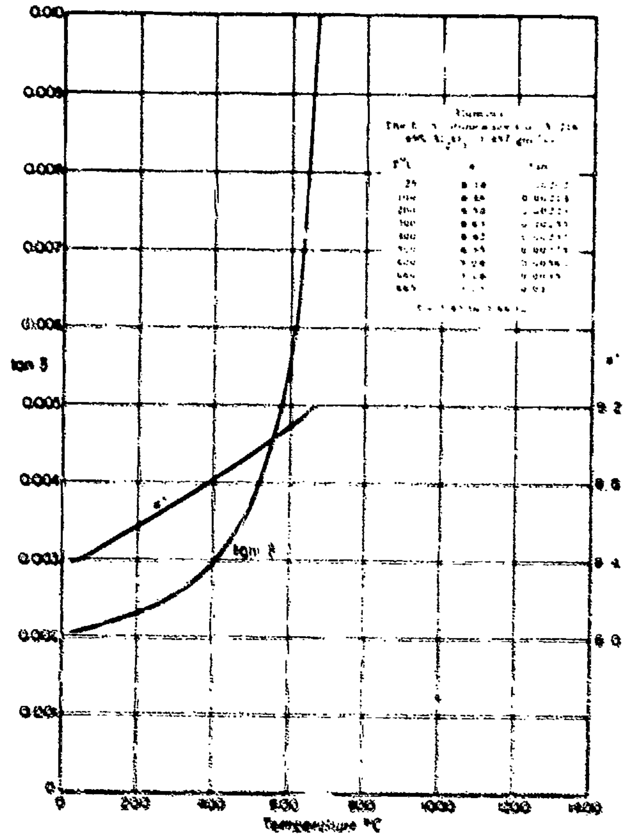
Aluminum oxide A-18 (multicrystalline)
Density 3.676 g/cm^3

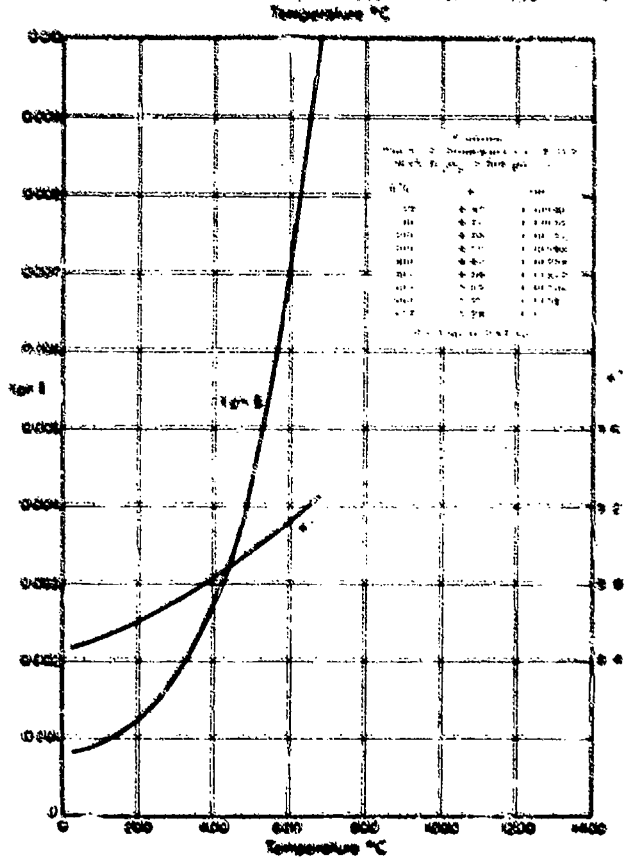
Steatit-Magnesia Aktiengesellschaft

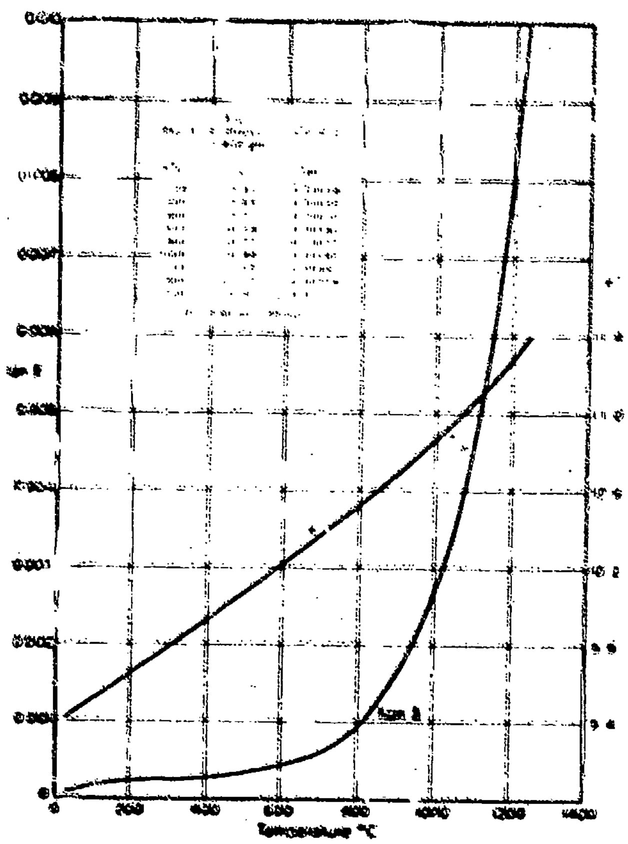


Alumina (cont.)

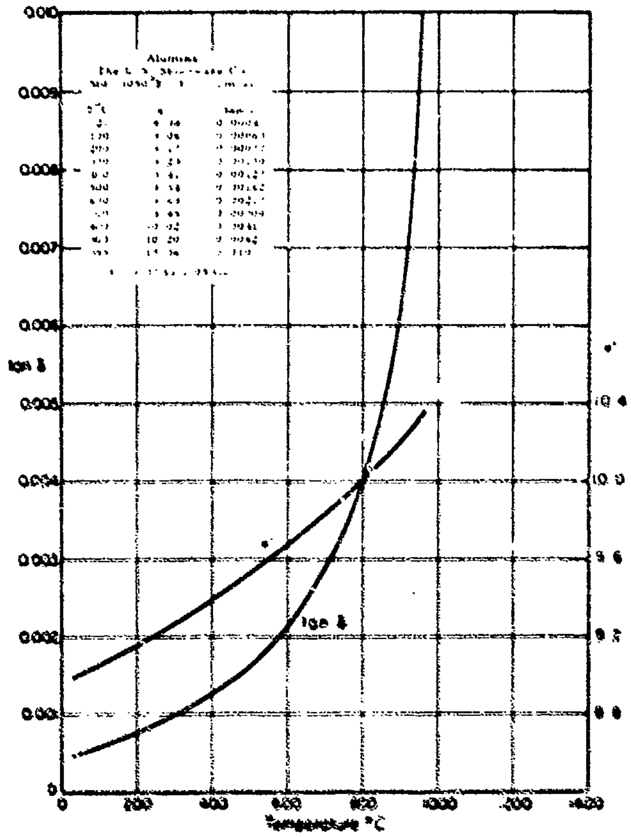


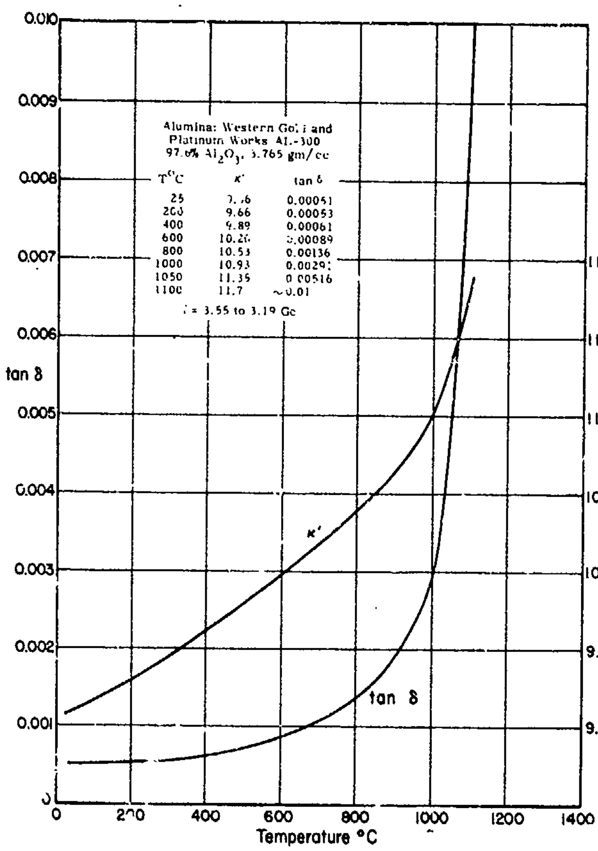






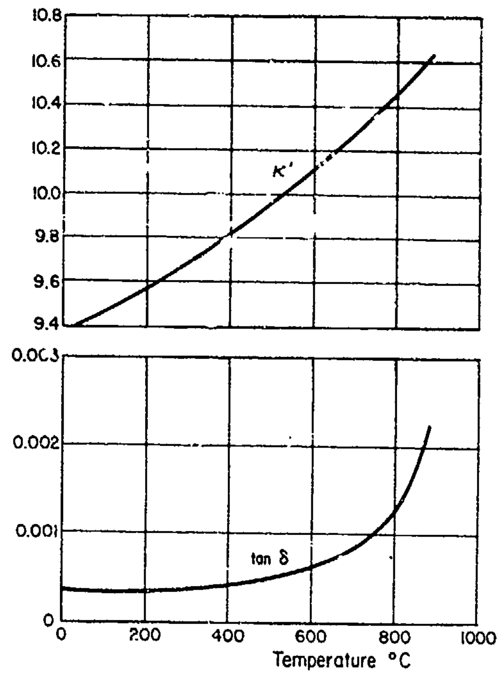
Alumina (cont.)





Alumina: Western Gold and Platinum

AL-300 modified
Density 3.771 g/cm^3
4.1 to 3.85 GHz

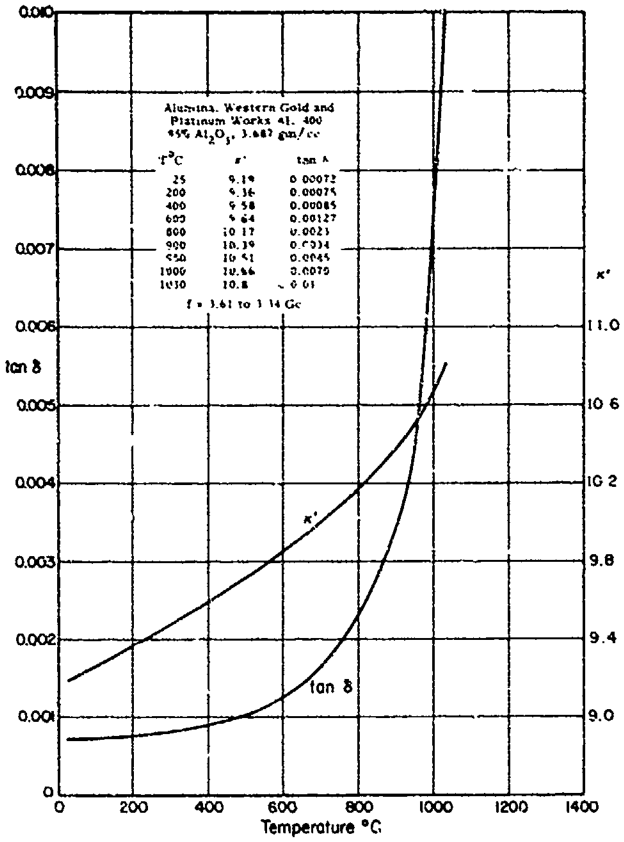


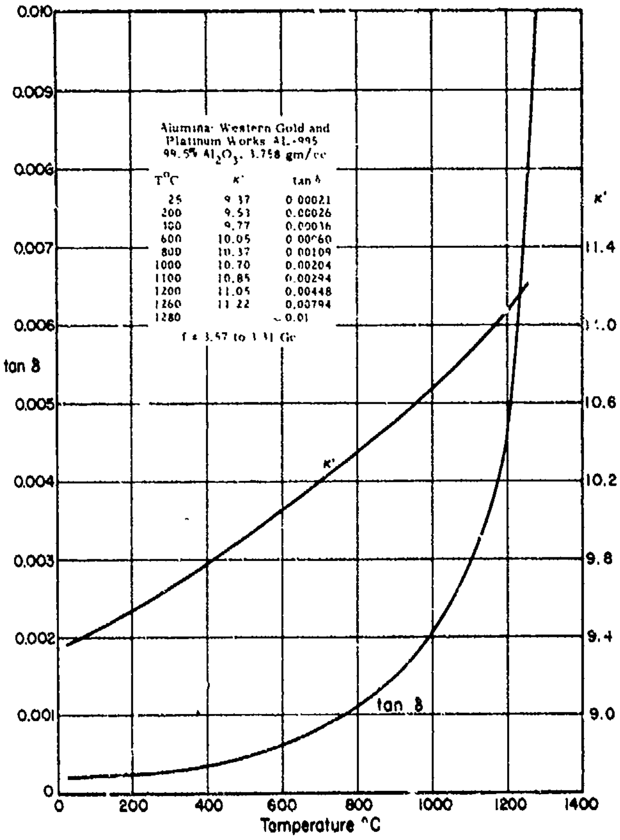
T°C	κ'	tan δ
25	9.39	.00037
122	9.48	.00037
185	9.55	.00038
258	9.63	.00038
339	9.74	.00041
393	9.79	.00045
500	9.95	.00055
572	10.08	.00064
788	10.43	.00120
881	10.63	.00219

At 25°C

f (Hz)		
10^7	9.44	.00012
10^9	9.40	.00035
3×10^9	9.39	.00037
8.5×10^9	9.38	.00046

Alumina (cont.)





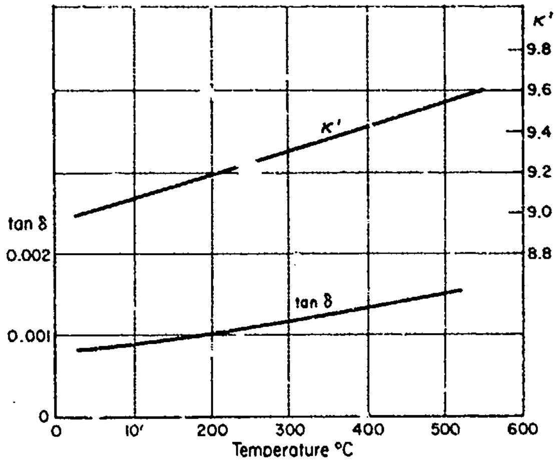
Aluminum oxide, AL-500

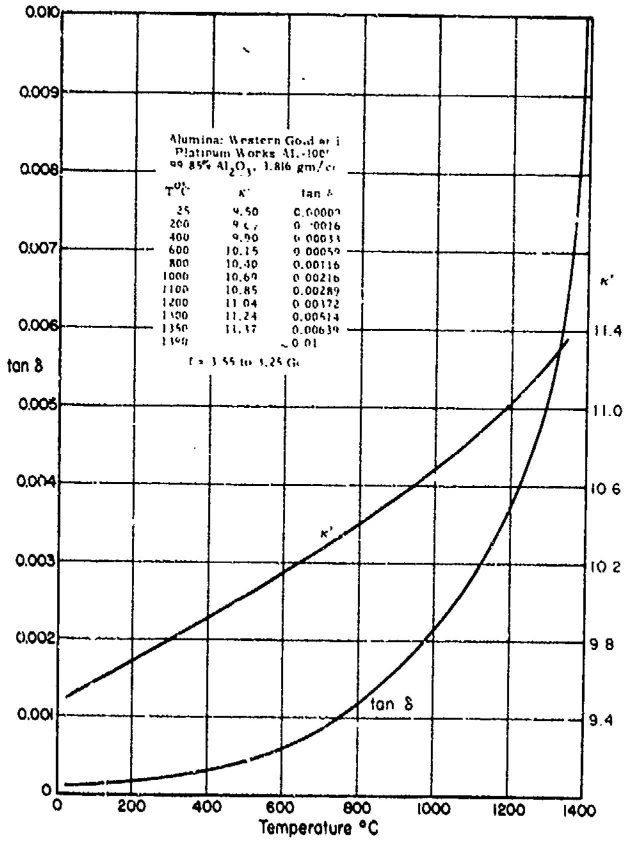
Western Gold and Platinum (multicrystalline)

Density 3.665 g/cm^3

At 25°C

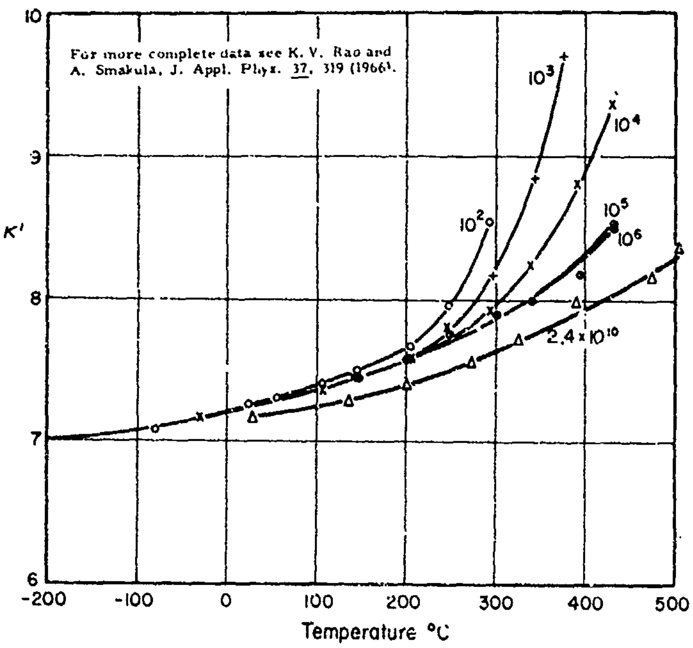
f (Hz)	κ'	tan δ
10^7	9.07	.00026
10^9	9.03	.00062
3×10^9	9.02	.00070
8.5×10^9	see the graph below	

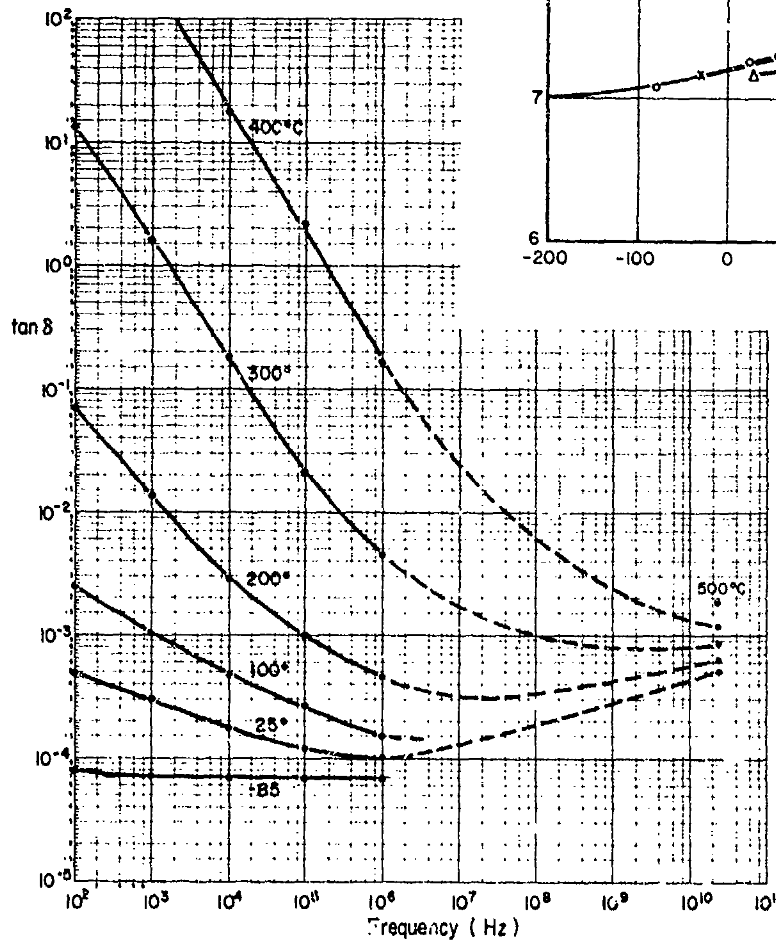




Barium fluoride
Single crystal

Massachusetts Institute of Technology
Crystal Physics Laboratory

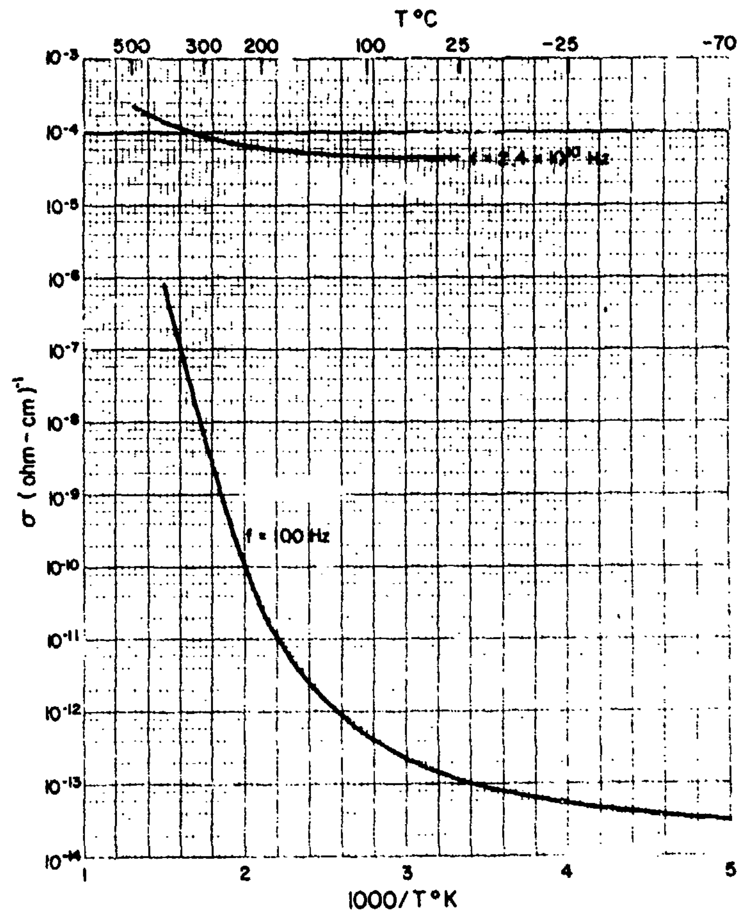




Barium fluoride (cont)

Single Crystal

Massachusetts Institute of Technology
Crystal Physics Laboratory



Beryllium oxide
BeO crystal KSC 7011A
Electronic Space Products Inc.

E $\parallel$ c axis

10^2 to 10^7 Hz

$\kappa' = 7.41 \pm 0.1$

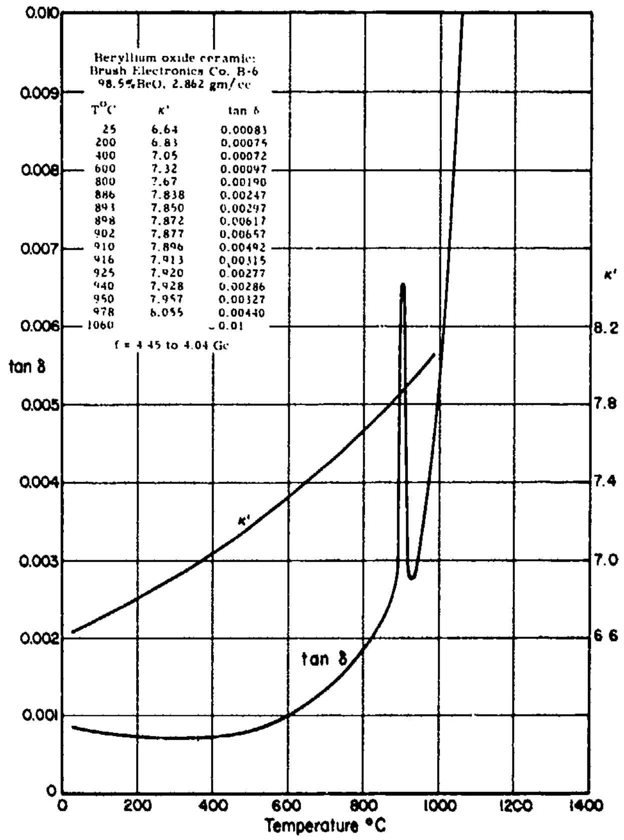
$\tan\delta < 0.0006$

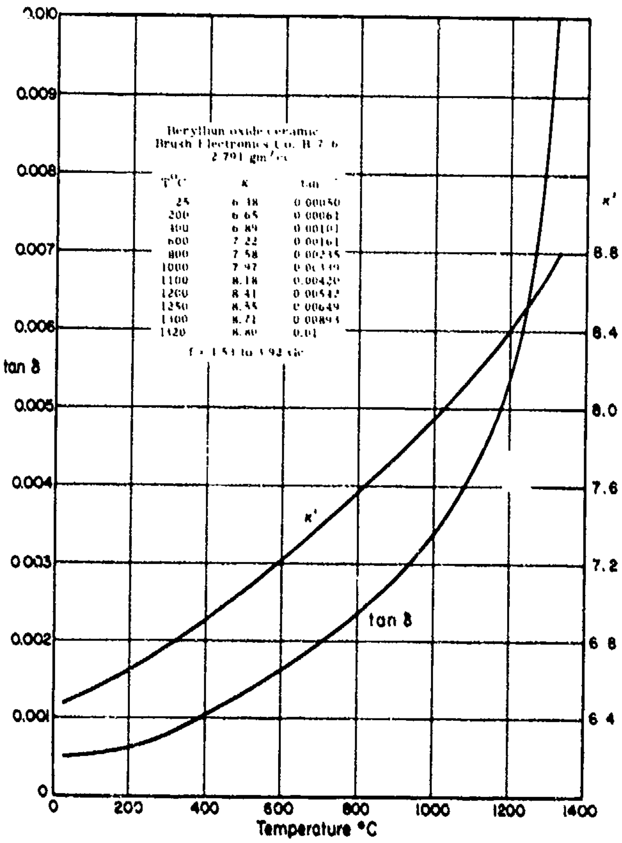
Beryllium oxide (cont.)

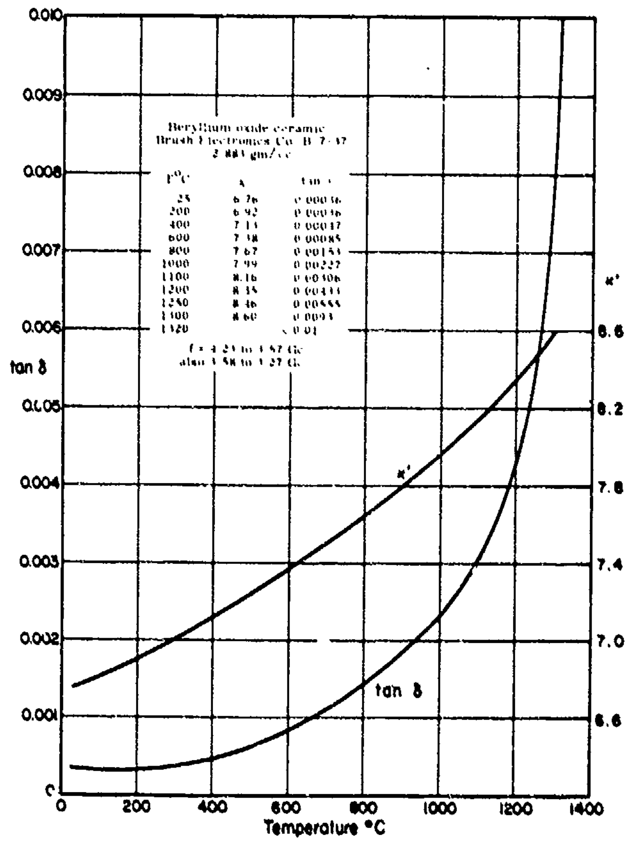
American Lava
AlSiMag 754 (99.5% BeO)
Density 2.851 g/cm^3

8.52 GHz

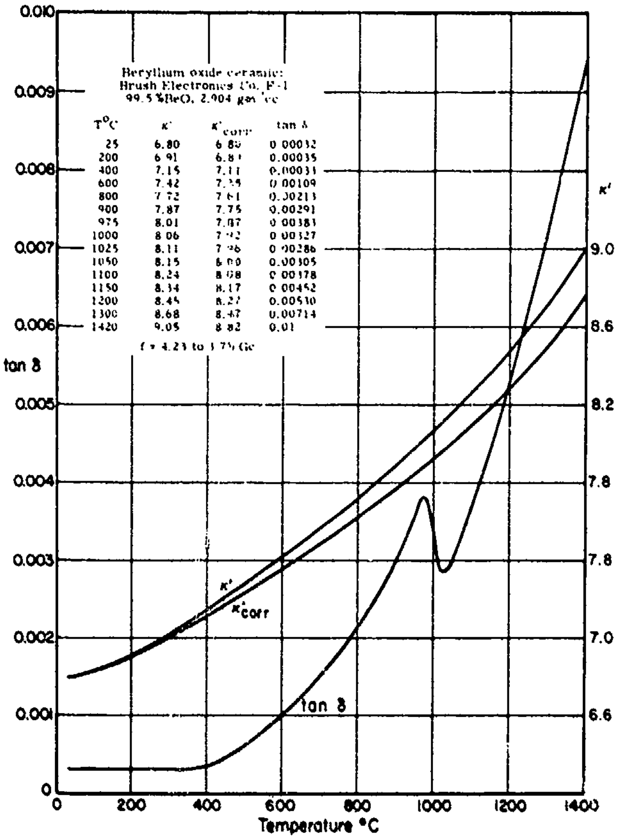
$T^{o}C$	κ'	tan δ
25	6.86	.00031
300	6.98	.00055
500	7.13	.00062







Beryllium oxide (cont.)

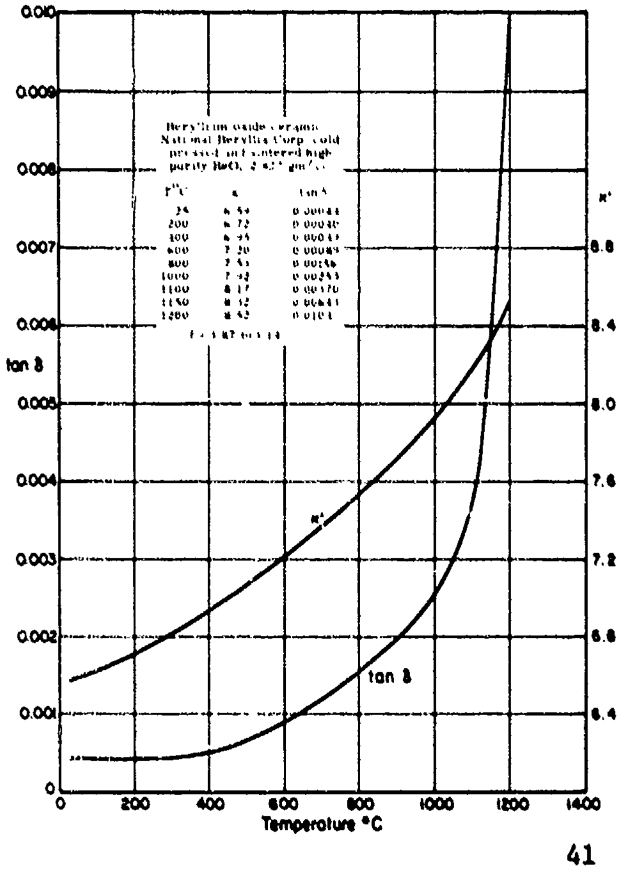


Coors Porcelain Co.

Beryllia BD98

8.52 GHz

$T^{o}C$	κ'	tan δ
25	6.67	.00050
300	6.87	.00072
500	7.13	.00102

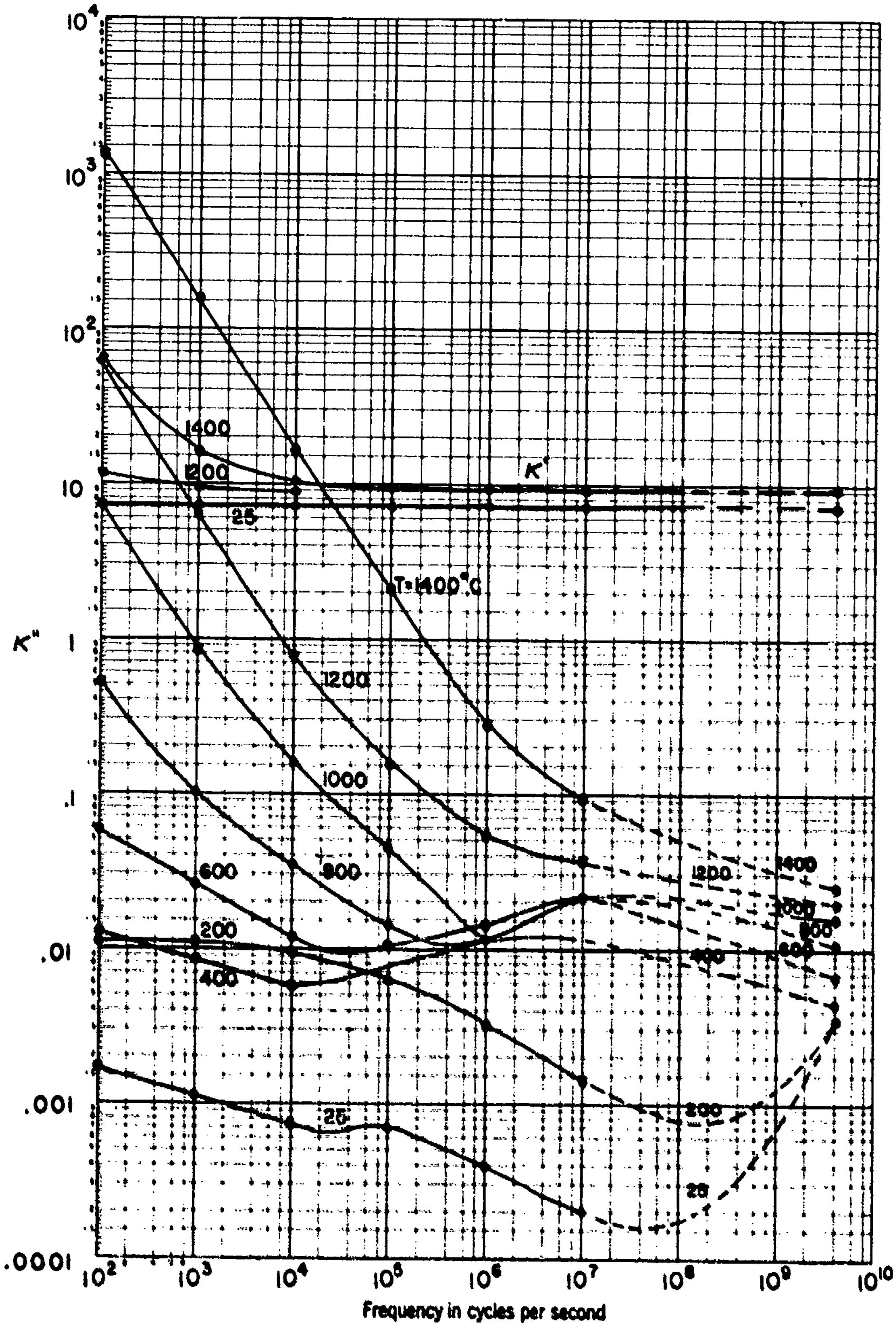


National Beryllia Corp.

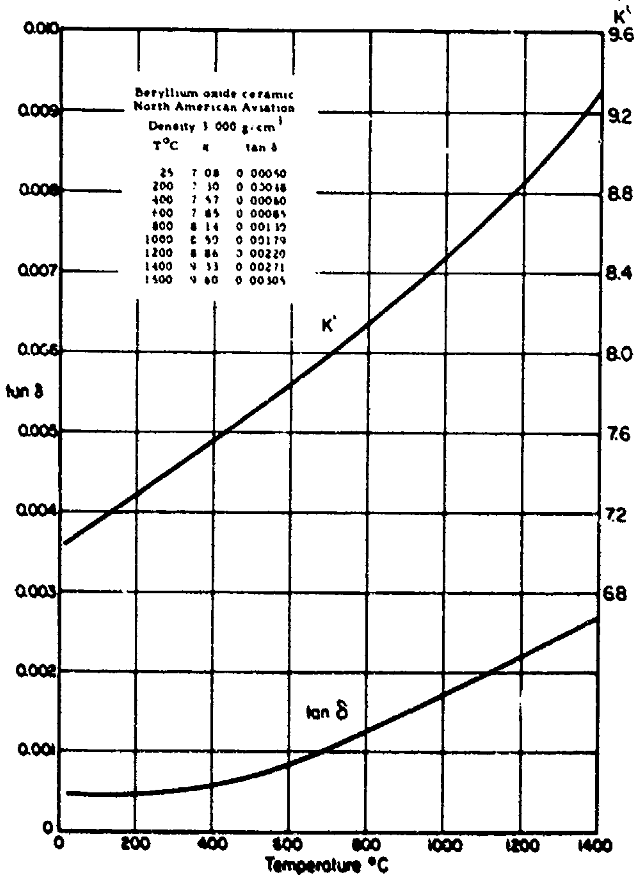
Berlox

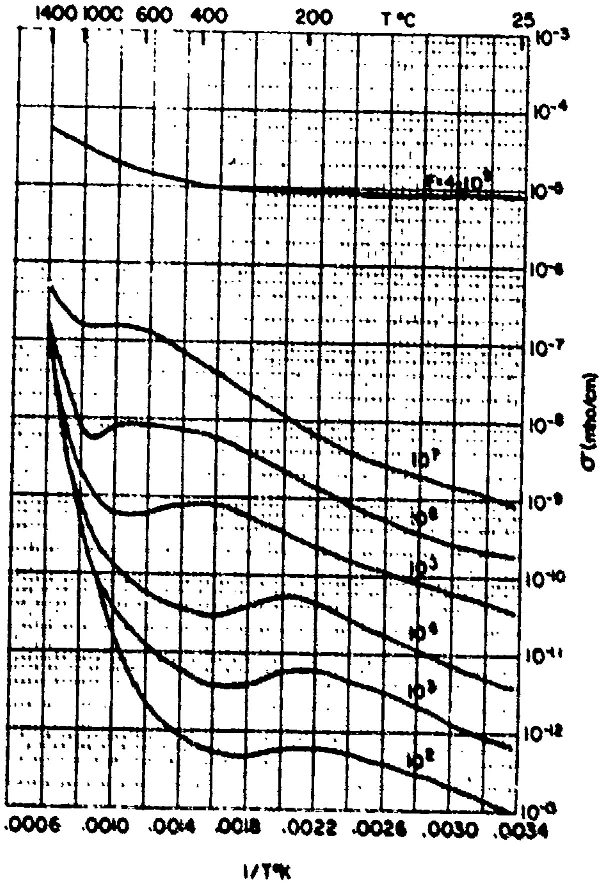
8.52 GHz

$T^{o}C$	κ'	tan δ
25	6.64	.00043
300	6.77	.00068
500	6.98	.00093


10⁴
10³
10²
10
1
.1
.01
.001
.0001
K''
K'
T=1400°C
1400
1200
1000
800
600
400
200
25
10²
10³
10⁴
10⁵
10⁶
10⁷
10⁸
10⁹
10¹⁰
Frequency in cycles per second

Beryllium oxide, multicrystal



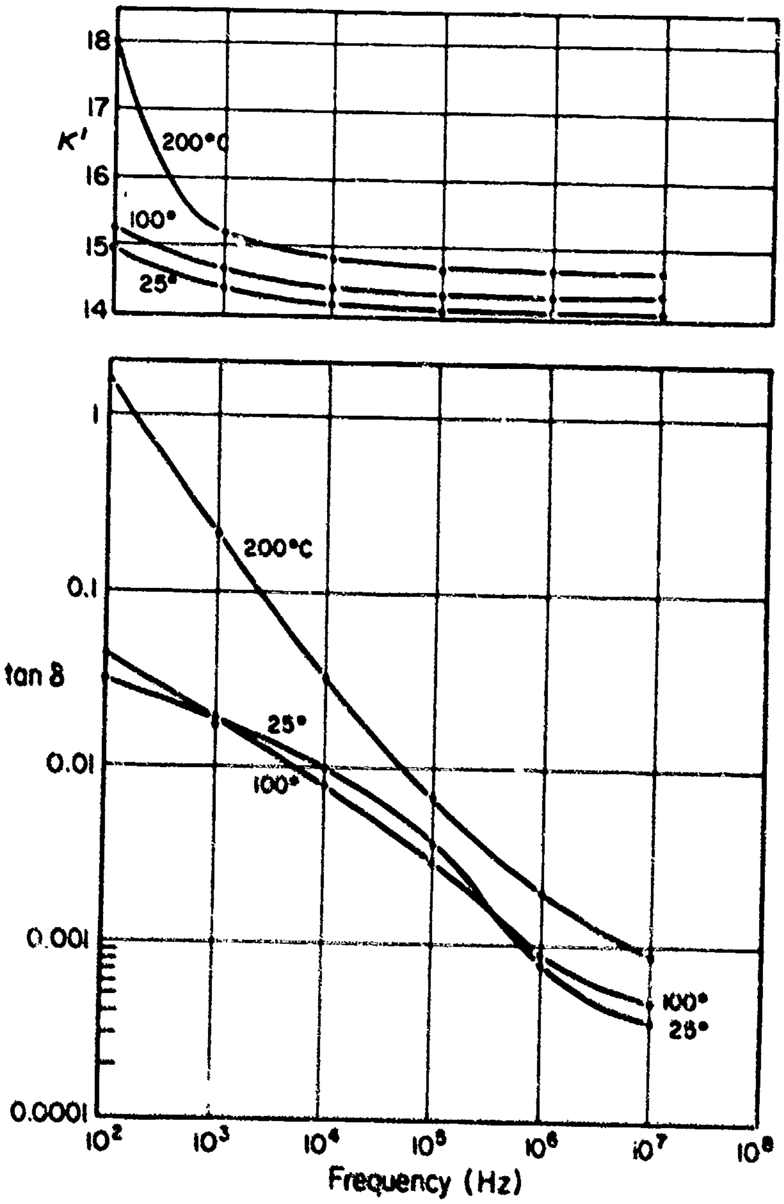


Beryllium silicate crystal KSC 7013 Electronic Space Products Inc.

E ∥ optic axis

f (Hz)	κ'	tan δ
10^2	5.1 ± .5	.0025
10^5	"	.0003 ± 2

$Bi_4Si_3O_{12}$ ceramic Laboratory for Insulation Research

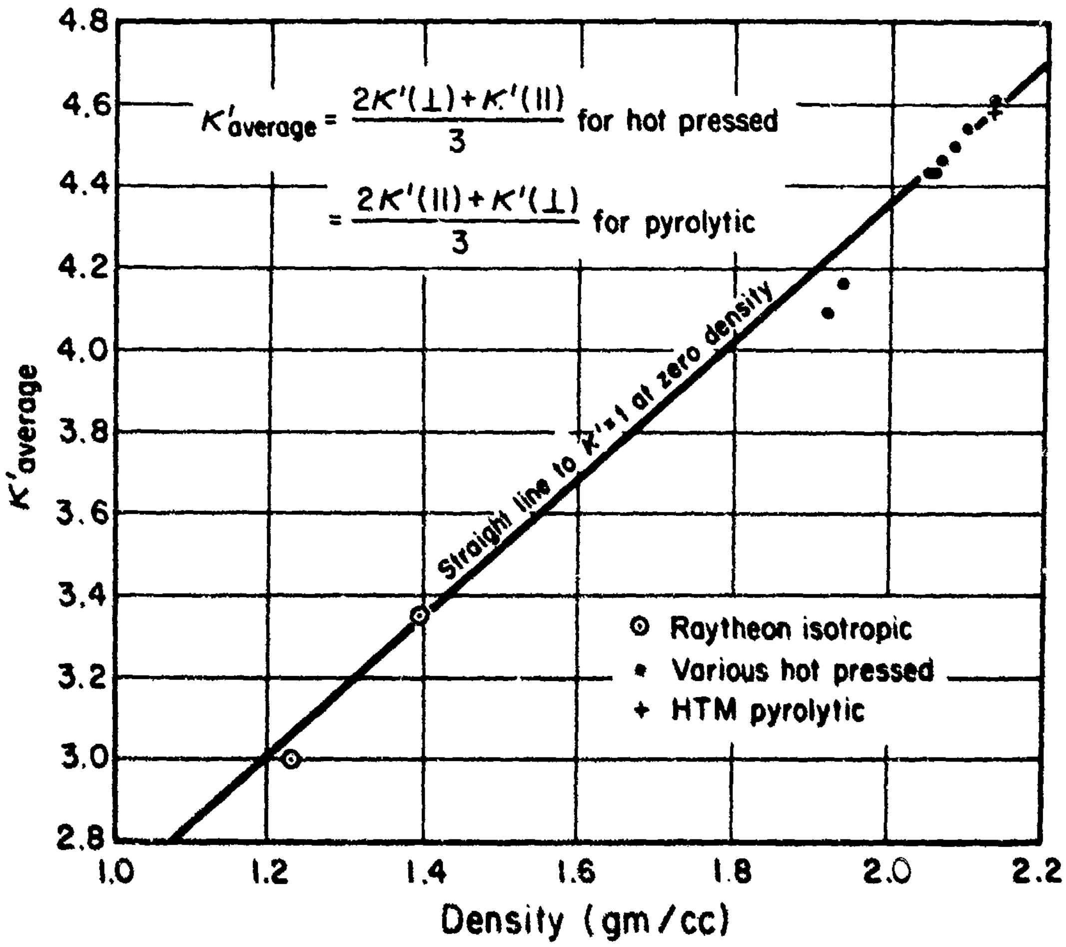


Boron nitride, hexagonal,

3000°C sublimes

Average dielectric constant versus density

X-ray density 2.25 g/cm^3



Boron nitride

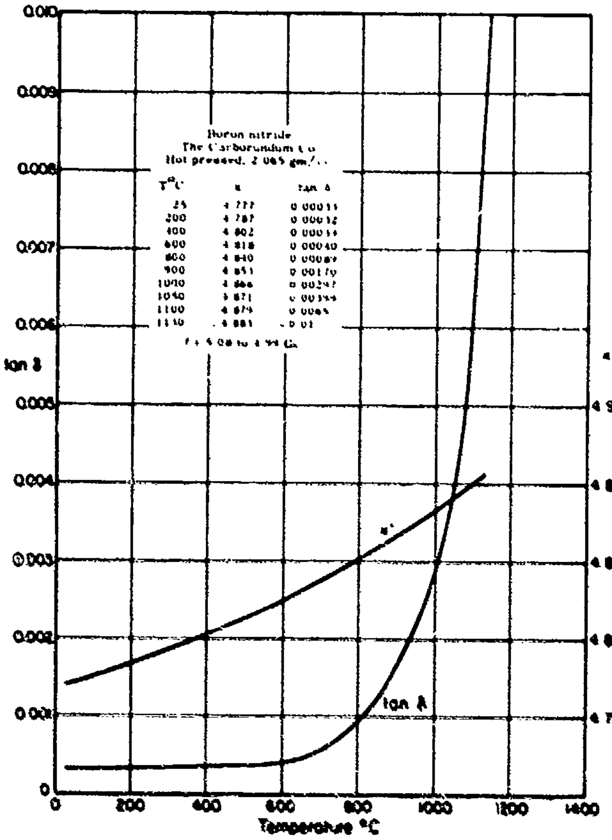
(hot-pressed, after vacuum treatment)

Density in g/cm^3

Battelle Memorial Institute

8.52 GHz, 25°C

Sample	Density	κ	tan δ
115H7	—	4.37	.00030
118H7	2.132	4.87	.00025


Boron nitride
0.010
0.009
0.008
0.007
0.006
tan δ
0.005
0.004
0.003
0.002
0.001
0
4.92
4.88
4.84
4.80
4.76
tan δ
0
200
400
600
800
1000
1200
1400
Temperature °C

Boron nitride, hot-pressed

Grade A, 25°C

Carborundum

All tan δ values are multiplied by 10^4

Sample No.	Density (g/cm^3)	Field direct.	(Hz)	10^2	10^3	10^4	10^5	10^6	10^7	10^8
1	2.084	unknown	κ	4.13	4.12	4.090	4.087	4.086	4.080	4.08
			tanδ	11.8	10.4	7.9	4.3	3.1	2.7	2.6
2	2.040	⊥	κ	4.40	4.40	4.39	4.39	4.39	4.38	
			tanδ	8.7	6.3	6.0	3.1	1.8	1.0	
3	2.066	∥	κ	3.99	3.99	3.98	3.98	3.98	3.97	
			tanδ	6.9	5.6	4.5	3.0	2.4	1.1	
			(Hz)	$3x10^8$	10^9	$3x10^9$	$8.5x10^9$	$1.4x10^{10}$	$2.4x10^{10}$	
4	(various not meas.)	unknown	κ	4.46	4.46	4.46		4.6	4.61	
			tanδ	4.0	3.3	3.4		5.8	3.5	
5	2.099	unknown	κ				4.605			
			tanδ				20			
6	2.091	⊥	κ	4.62	4.615	4.599				
			tanδ	2.6	3.7	3.8				
7	2.097	mixed	κ	4.36	4.359	4.352				
			tanδ	2.2	1.3	1.5				
8	2.069	⊥	κ				4.586			
			tanδ				6.4			
9	2.077	⊥	κ				4.550			
			tanδ				3.6			
9	"	∥	κ				4.268			
			tanδ				4.5			
10		⊥	κ					4.268		
			tanδ					4.5		
11	2.093	⊥	κ					4.53		
			tanδ					4.5		
11	"	∥	κ					4.28		
			tanδ					10.4		
12	2.090	⊥	κ						4.56	
			tanδ						5.3	
13	2.095	⊥	κ						4.54	
			tanδ						4.6	
13	"	∥	κ						4.24	
			tanδ						3.2	

Boron nitride, hot-pressed
Grade HP, 25°C

The Carborundum Company
Refractories & Electronics Division
Whirlpool Technical Center
Niagara Falls, N.Y., 14302

All tan δ values multiplied by 10^4

Sample No.	Density (g/cm^3)	Field direct.		(Hz) 10^2	10^3	10^4	10^5	10^6	10^7	10^8
1	2.120	unknown	κ	4.59	4.56	4.54	4.54	4.54	4.54	4.54
			tanδ	8.5	3.58	2.30	2.3	2.3	2.8	3.5
2	1.762	⊥	κ	4.14	4.02	3.97	3.96	3.96	3.96b	
			tanδ	414	174	41.6	9.9	3.4	2.0	
3	2.131	∥	κ	4.71	4.64	4.54	4.46	4.40	4.32	
			tanδ	100	110	120	125	141	123	

Sample No.	Density (g/cm^3)	Field direct.		(Hz) $3x10^8$	10^9	$3x10^9$	$8.5x10^9$	$1.4x10^{10}$	$2.4x10^{10}$
4	(various not meas.)	unknown	κ	4.59	4.59	4.59	4.39	4.62	4.57
			tanδ	2.7	3.5	4.2	6.55	6.0	6.0
5	1.999	unknown	κ						
			tanδ						
6	2.033	⊥	κ	4.47	4.468	4.457			
			tanδ	5.3	4.6	6.0			
7	1.748	mixed	κ	3.88	3.880	3.876			
			tanδ	4.1	4.7	4.0			
8	2.111	⊥	κ				4.584		
			tanδ				6.0		
9	2.061	⊥	κ				4.553		
			tanδ				7.1		
9	"	∥	κ				4.507		
			tanδ				7.7		
10	2.117	⊥	κ					4.75	
			tanδ					8.0	
11	2.063	⊥	κ					4.55	
			tanδ					8.7	
11	"	∥	κ					4.51	
			tanδ					8.8	
12	2.118	⊥	κ						4.69
			tanδ						8.5
13	2.066	⊥	κ						4.6[illegible]
			tanδ						[illegible]
13	"	∥	κ						4.68
			tanδ						9.[illegible]

Boron nitride, hot-pressed, with silica

Grade M, 25°C

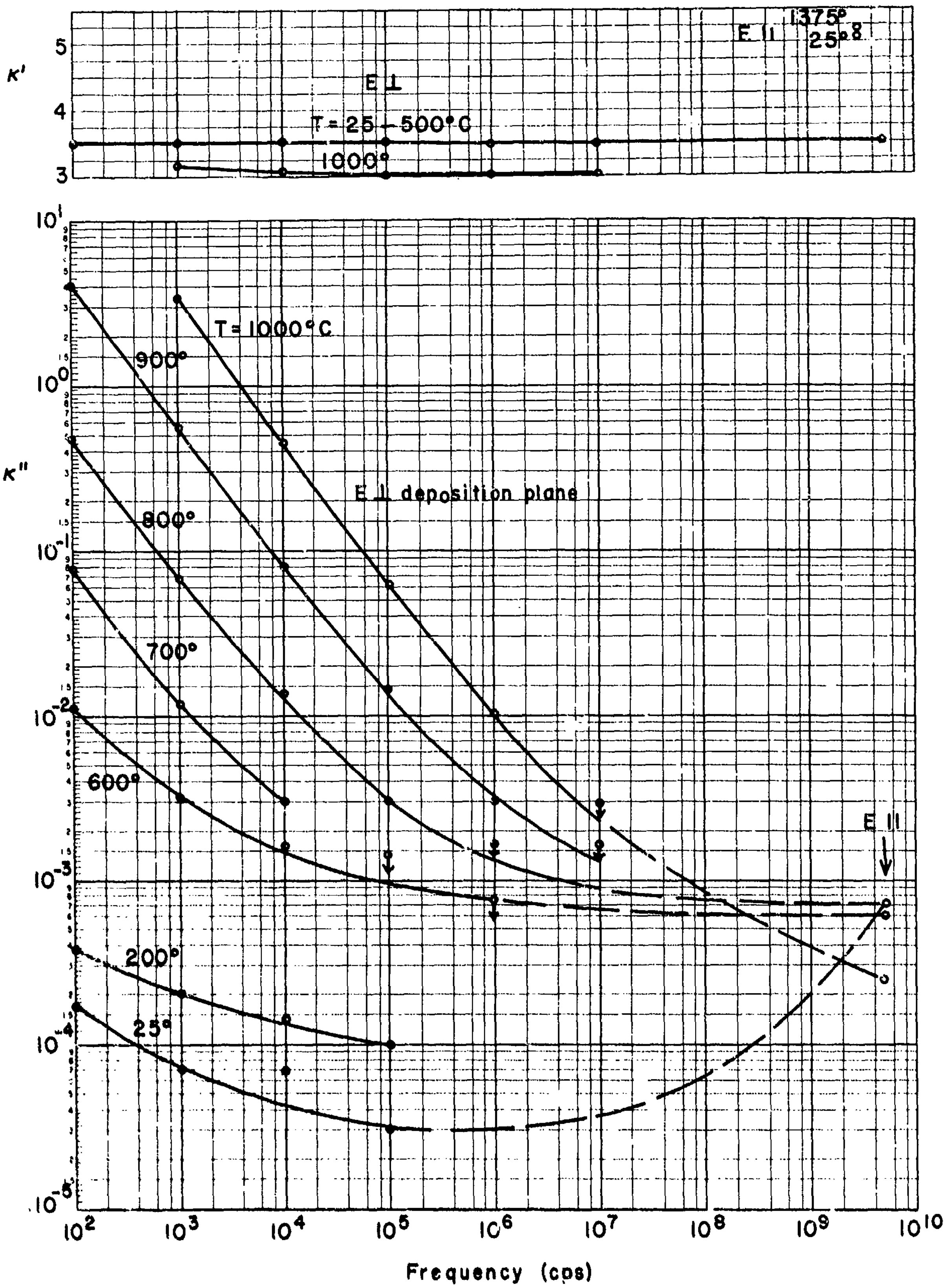
Carborundum

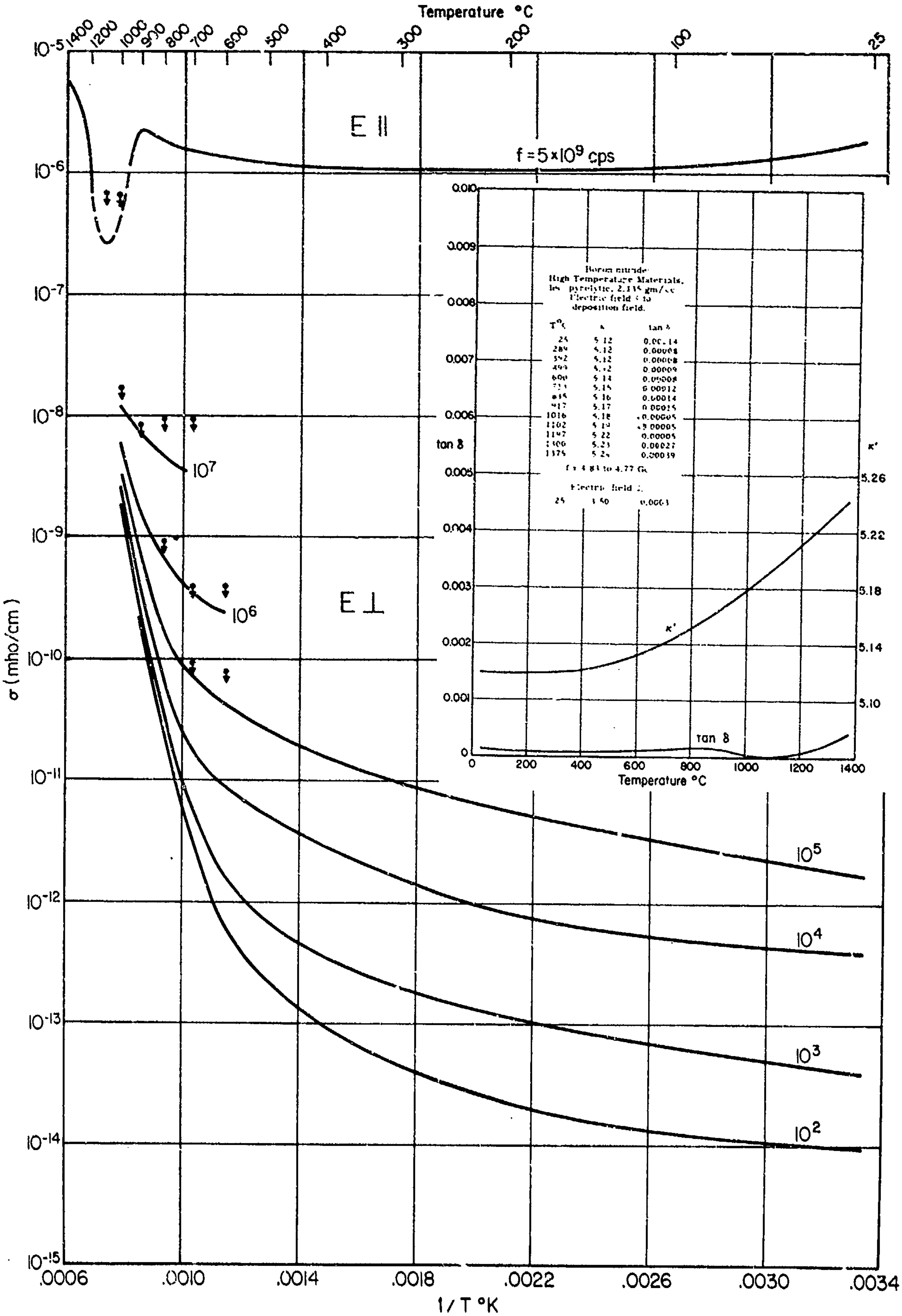
All tan δ values multiplied by 10^4

Sample No.	Density (g/cm^3)	Field direct.		(Hz) 10^2	10^3	10^4	10^5	10^6	10^7	10^8
1	2.143	unknown	κ	3.71	3.70	3.69	3.69	3.69	3.68	3.68
			tanδ	4.0	2.78	2.22	2.07	1.63	1.8	2.3
2	2.107	⊥	κ	4.34	4.33	4.32	4.30	4.30	4.30	
			tanδ	16.9	14.3	10.5	6.6	3.7	1.9	
3	2.109	∥	κ	3.76	3.76	3.76	3.75	3.75	3.75	
			tanδ	7.4	7.0	6.7	4.6	3.4	3.6	

Sample No.	Density (g/cm^3)	Field direct.		(Hz) 3×10^8	10^9	3×10^9	8.5×10^9	1.4×10^{10}	2.4×10^{10}
4	(various not meas.)		κ	4.24	4.24	4.24		4.32	
			tanδ	2.8	3.1	3.7		5.5	
5	2.145		κ				4.328		
			tanδ				4.1		
6	2.137	⊥	κ	4.27	4.27	4.255			
			tanδ	3.8	4.9	4.9			
7	2.118	mixed	κ	3.99	3.992	3.983			
			tanδ	3.9	4.5	5.2			
8	2.095	⊥	κ				4.192		
			tanδ				6.6		
9	2.120	⊥	κ				4.332		
			tanδ				6.2		
9		∥	κ				3.668		
			tanδ				8.5		
10	2.125	⊥	κ					4.23	
			tanδ					5.4	
11	2.123	⊥	κ					4.295	
			tanδ					11.0	
11	"	∥	κ					3.63	
			tanδ					7.8	
12	2.066	⊥	κ						4.22
			tanδ						6.1
13	2.121	⊥	κ						4.28
			tanδ						7.9
	"	∥	κ						3.64
			tanδ						10.5

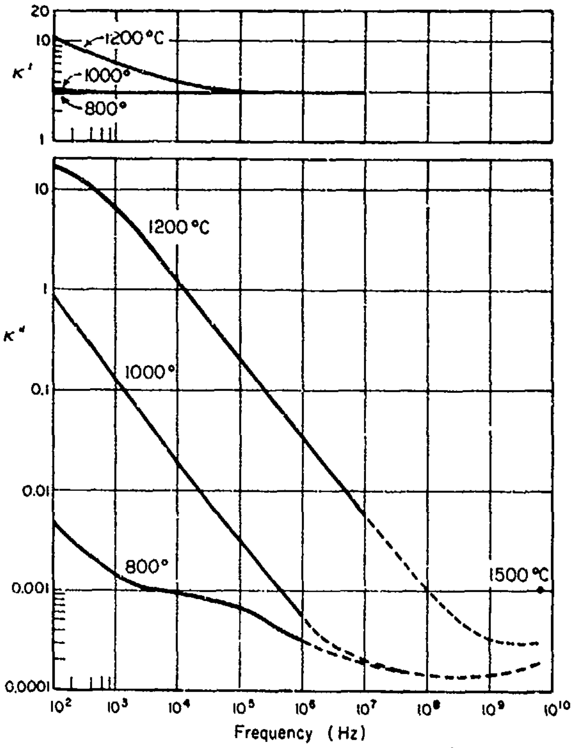
BN, pyrolytically deposited, High-Temperature Materials, Inc., "Boralloy." The microwave data show a small peak possibly due to loss of impurities (perhaps OH ions) at about 800°C. Graphite electrodes and prepurified N_2 used in low-frequency measurements which showed variations among different samples.




Temperature °C
1400
1200
1000
900
800
700
600
500
400
300
200
100
25
E ||
f = 5×10⁹ cps
E ⊥
10⁷
10⁶
10⁵
10⁴
10³
10²
σ (mho/cm)
10⁻⁵
10⁻⁶
10⁻⁷
10⁻⁸
10⁻⁹
10⁻¹⁰
10⁻¹¹
10⁻¹²
10⁻¹³
10⁻¹⁴
10⁻¹⁵
.0006
.0010
.0014
.0018
.0022
.0026
.0030
.0034
1/T °K
Boron nitride
High Temperature Materials,
deposition field.
tan δ
κ'
0.010
0.009
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
5.26
5.22
5.18
5.14
5.10
0
200
400
600
800
1000
1200
1400
Temperature °C

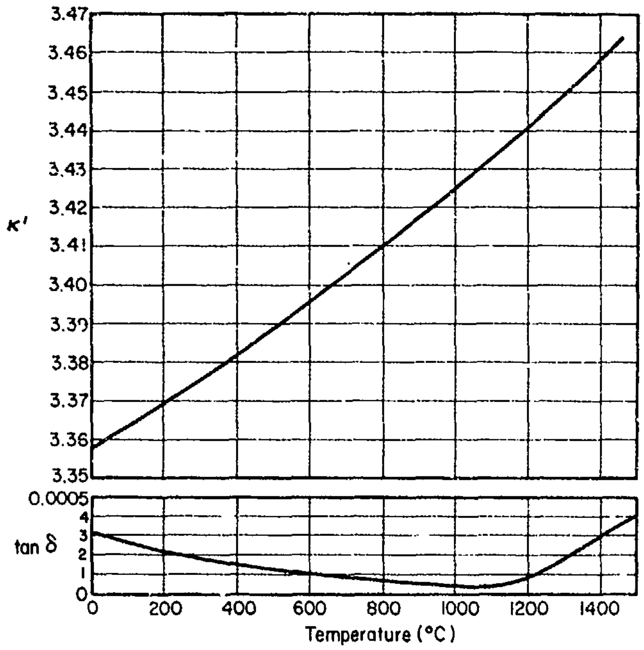
Pyrolytic boron nitride Raytheon

Density 1.23 g/cm^3

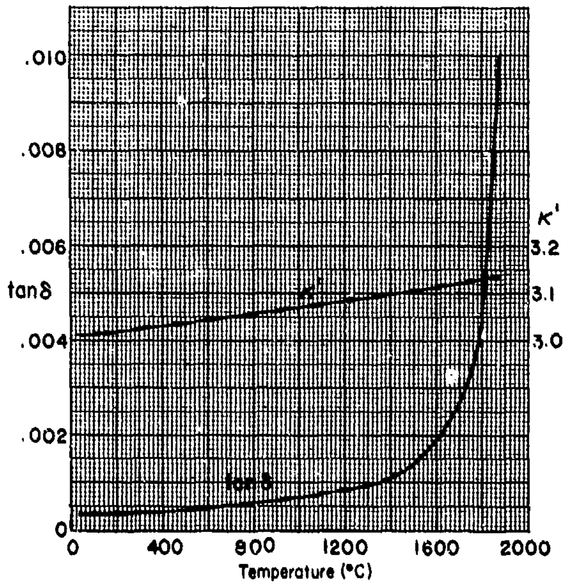


At 5.74 to 5.65 GHz

Density 1.398 g/cm^3



Density 1.23 g/cm^3
At 9.21 to 9.04 GHz



Post-treated samples, measured at 8.52 GHz, 25°C

Density (g/cm^3)	κ	tan δ
1.233	2.994	.00008 ± .00002
1.237	3.013	.00005 ± .00003

Sample 2A + 2B, density at 25°C 1.381

	5.07 to 5.00 GHz	
T°C	κ	tan δ
25	3.199	<.0002
200	3.212	<.0002
400	3.226	<.0002
600	3.241	.0002 ± .0001
800	3.255	.0002 ± .0001
1000	3.272	.0002 ± .0001
1200	3.288	.0002 ± .0001
1300	3.297	.0003 ± .0002
1400	3.309	.0007 ± .0004

Test for anisotropic effects at 8.52 GHz, 25°C, by rotation and reversal of sample:

$\kappa_{max} = 3.0018$

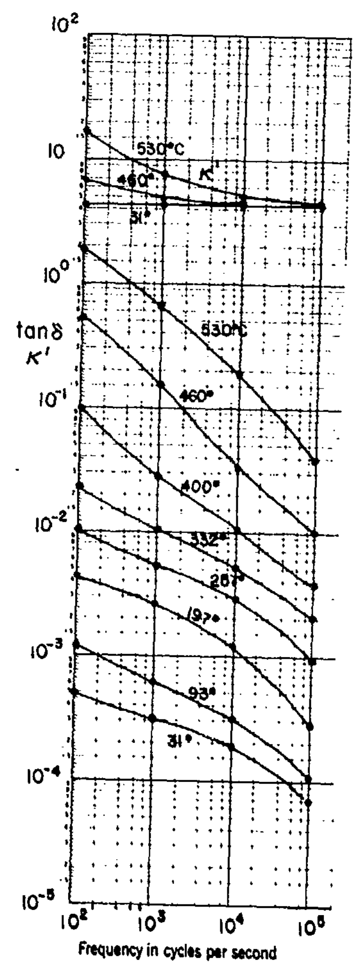
$\kappa_{min} = 2.9894$

Boron nitride

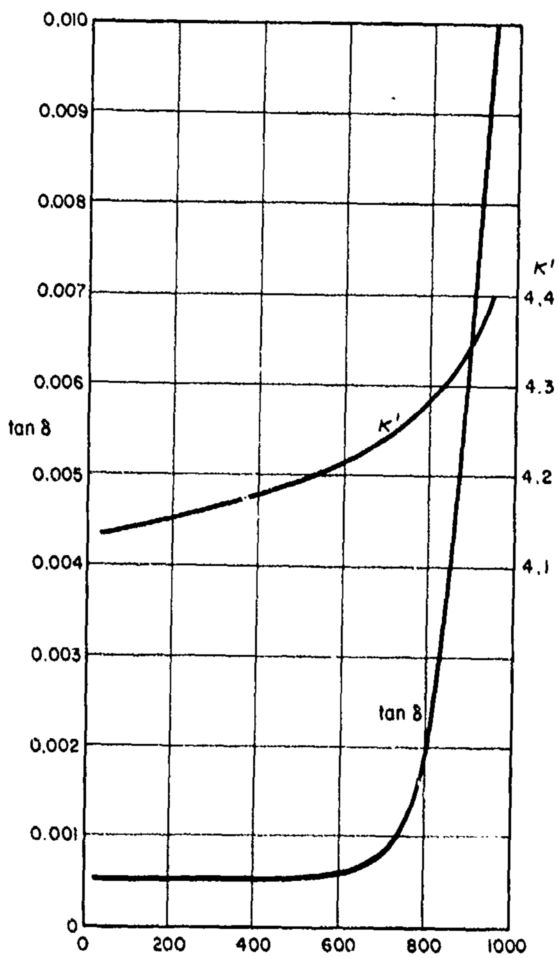
Pyrolytic laminate,
Union Carbide

T°C		
25	5.15±.05	.00025±.00005
173		.00025±.0001
225		
341		
470		
610		
800		
978		.0003±.0001

Boron nitride, hot-pressed
Grade HD0056



Boron nitride,
Grade HD0086, density 1.940 g/cm^3,
5.17 to 4.96 GHz



Boron nitride, grade HD 0086

8.52 GHz

T°C	E	κ'	tan δ
25	‖	4.31	.00053
25	⊥	4.10	.00055
100	⊥	4.08	.00059
200	⊥	4.07	.00066
300	⊥	4.06	.00075
400	⊥	4.05	.00086
500	⊥	4.05	.00102

Grade HD 0092,
Density 1.9745 g/cm^3
At 8.52 GHz

κ_{min} = 3.993 tan δ = 0.00025
κ_{max} = 4.091 tan δ = 0.00026

At 4.54 to 4.47 GHz

T^oC	κ	tan δ
25	4.08	.00026
113	4.08	.0003
185	4.09	.0005
322	4.09	.00055
423	4.10	.00040
530	4.11	.00035
639	4.12	.00040
752	4.13	.00045
863	4.13	.00050
943	4.14	.00050
1021	4.15	.00055
1096	4.16	.00080
1170	4.16	.0013
1219	4.17	.0019
1287	4.18	.0034
1373	4.19	.0040
1427	4.20	.0028
1446	4.22	.0023
1460	4.24	.0044
1470	4.24	0046

Grade HD 0093
Density 1.9165 g/cm^3
At 8.52 GHz

κ' = 3.998 $\pm$ 0.002
tan δ = 0.00052

At 4.53 to 4.44 GHz

T^oC	κ	tan δ
25	4.003	.0005
207	4.048	.0004
393	4.072	.00045
513	4.088	.0004
593	4.101	.0007
798	4.146	.0030
852	4.166	.0052
891	4.204	.0040
1018	4.320	.0028
1077	4.479	.0057
1094	4.485	.0071
1110	4.54	.01
943	4.25	.0026
860	4.19	
25	4.01	

Density check after run 1.916

Grade HD 0094, at 8.52 GHz
Sample 2: density 1.303 g/cm^3

T^oC	κ	tan δ
25	3.004	.00033

Sample 1: density 1.307 g/cm^3

T^oC		
25	3.016	.00033
93	3.02$\pm$.03	.00030
192		.00035
339		.00037
471		.00040
602	3.04$\pm$.03	.00040
705		.00047
754		.00060
793		.00095
843		.0020
954		.0085
999		.0135

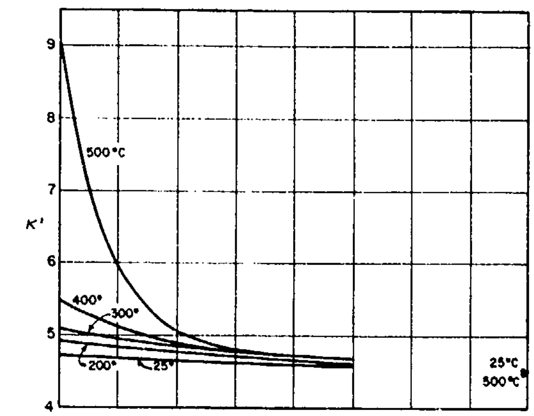
At 5.30 to 5.26 GHz
Density: 1.303 g/cm^3

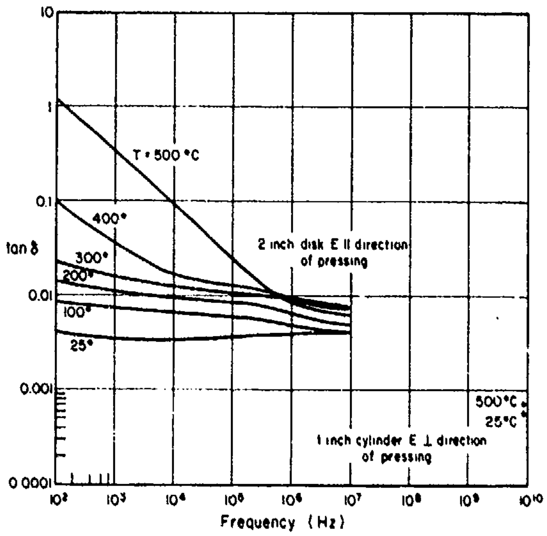
T^oC	κ	tan δ
25	3.004	.00033
120	3.008	.00037
203	3.012	.00039
325	3.018	.00044
404	3.021	.00043
498	3.026	.00046
601	3.032	.00046
721	3.039	.00065
812	3.047	.00186
884	3.053	.00447
908		>.01

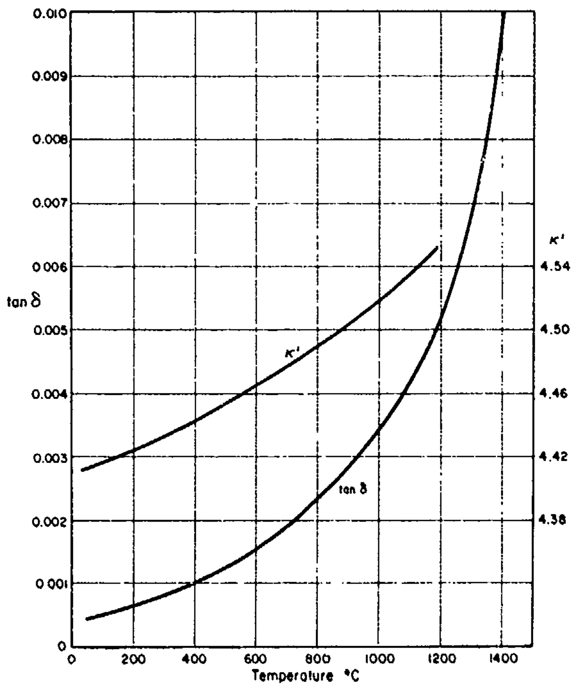
Hot-pressed boron nitride, grade HBN

Carbon Products Division
Union Carbide Corp.
(Formerly National Carbon Co.)

4.95 to 4.88 GHz







Density 2.054 g/cm^3

1" cylinder, 8.52 GHz

T°C	E	κ'	tan δ
25	⊥	4.38	.00050
25	∥	4.52	.00056
100	∥	4.52	.00056
200	∥	4.51	.00061
300	∥	4.50	.00064
400	∥	4.49	.00066
500	∥	4.48	.00073

Boron nitride, hot-pressed
Grade HBR

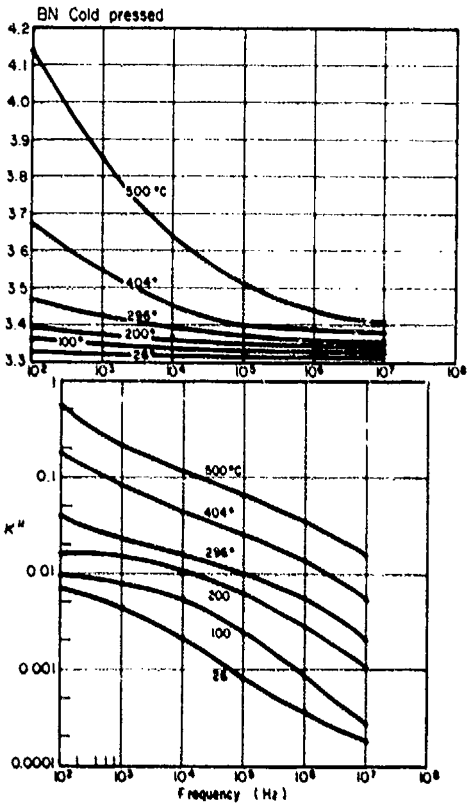
Union Carbide Corporation
Carbon Products Division

E ⊥ direction of pressing

T^oC		10^2	10^3	10^4	10^5	10^6	10^7
25	κ	4.77	4.77	4.76	4.76	4.76	4.76
	10^4 tan δ	18.2	7.1	4.9	1.5	1.4	0.9
100	κ	4.85	4.80	4.78	4.78	4.78	4.78
	10^4 tan δ	165	45.4	9.4	4.1	2.1	0.6
200	κ	5.26	4.96	4.85	4.82	4.81	4.81
	10^4 tan δ	596	277	101	39	5.4	23
300	κ	5.75	5.25	5.00	4.89	4.85	4.85
	10^4 tan δ	855	526	231	109	33.8	12.5
400	κ	6.75	5.70	5.21	5.00	4.88	4.87
	10^4 tan δ	28.0	11.57	4.95	2.3	1.2	.37
500	κ	8.07	6.46	5.62	5.31	5.08	4.93
	tan δ	1.994	.389	.109	.0419	024	.014

Boron nitride, Cold-pressed

Union Carbide Corporation



Rod sample, at 8.52 GHz

Density: 1.474 g/cm^3

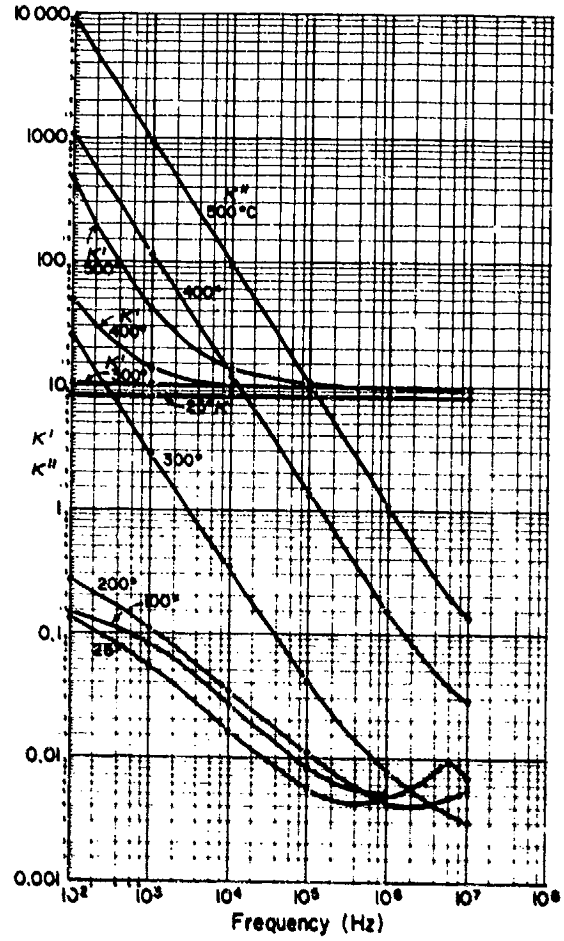
At 25^{o}C:

κ' = 3.412; tan δ = .00046

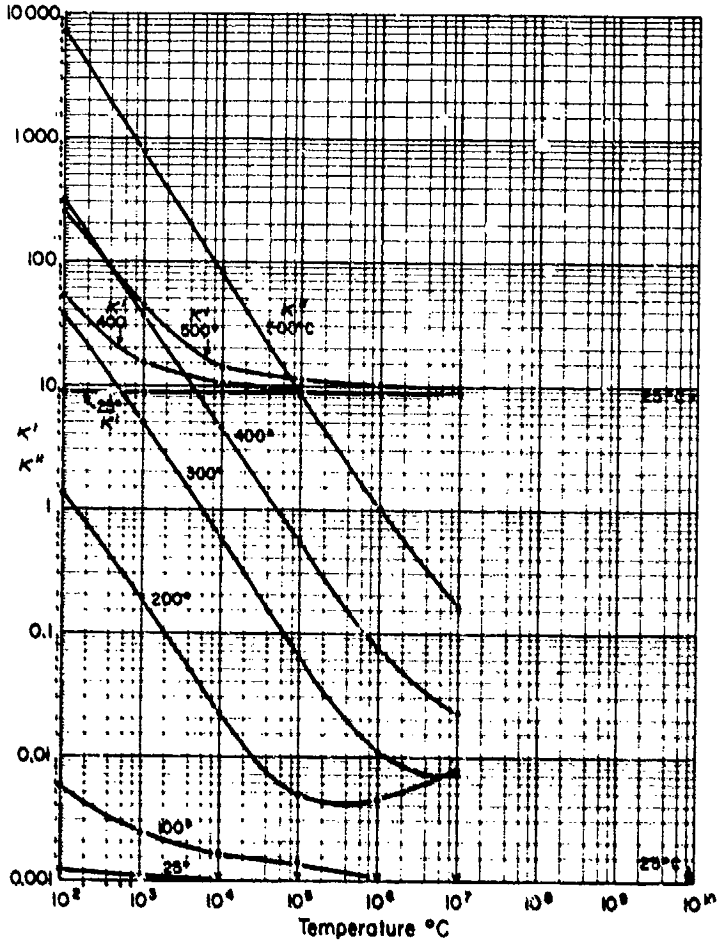
Calcium carbonate (calcite)

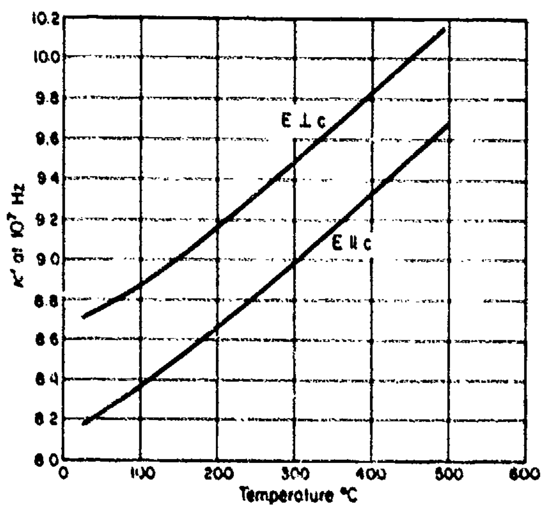
Single crystal mineral,
hexagonal, decomposes at 894°C

E ∥ c, crystal No. 1



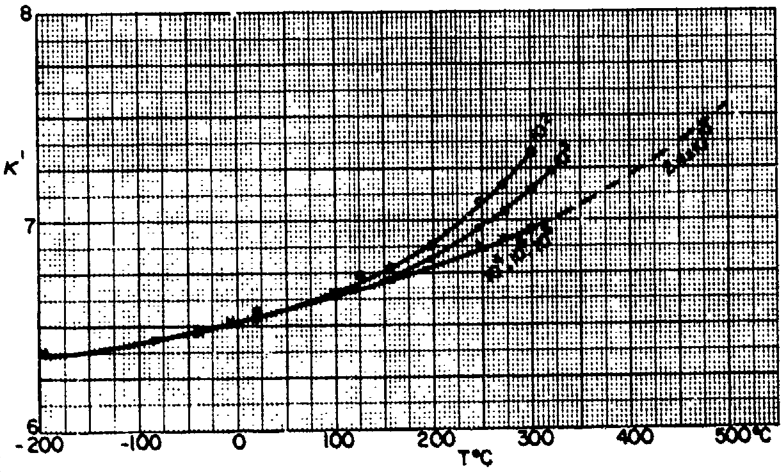
E ⊥ c, crystal No. 2

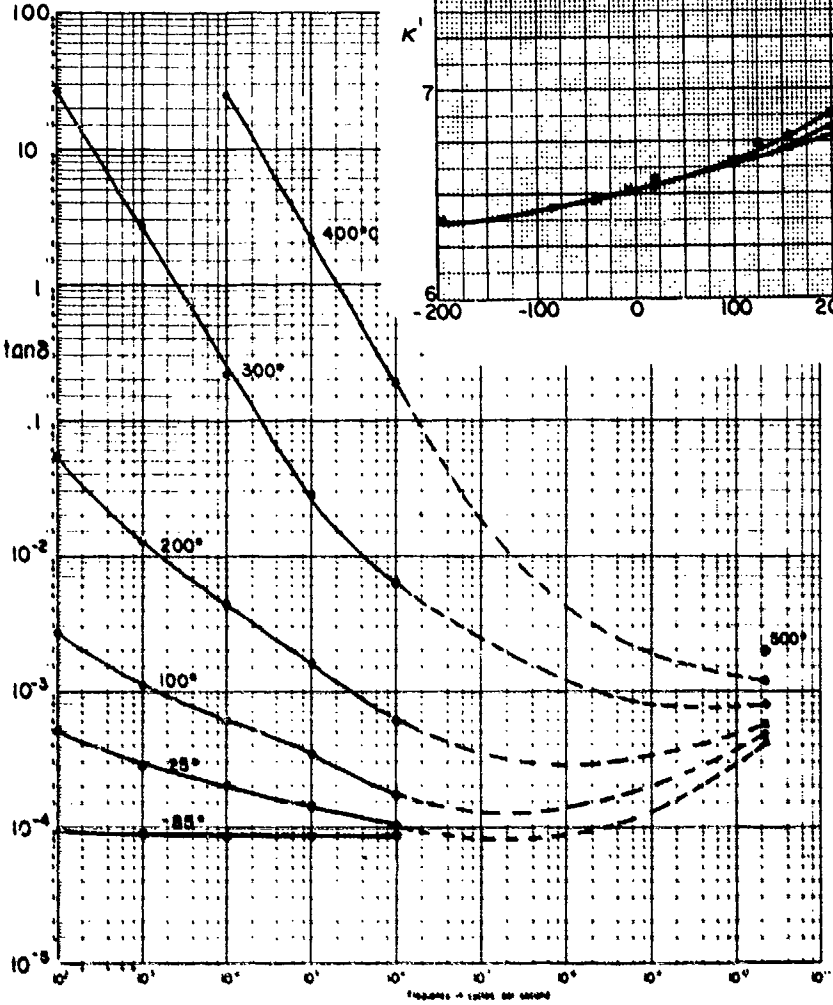


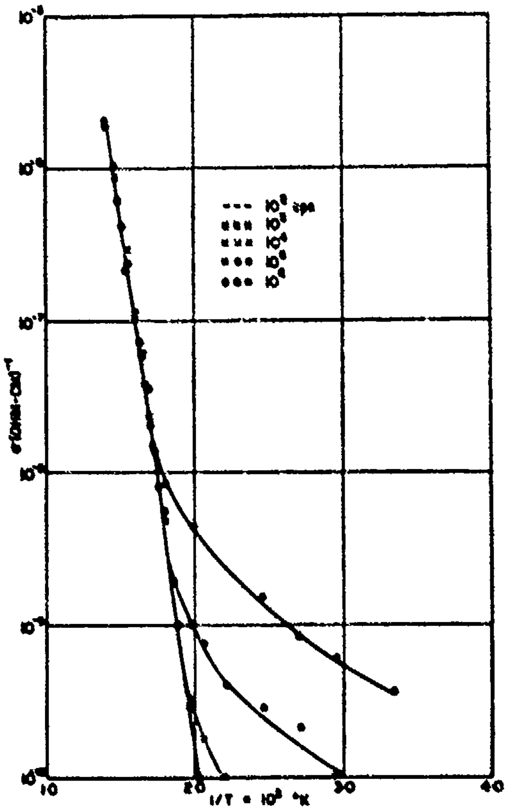


Calcium fluoride crystal
Single crystal, cubic, m.p. 1360°C

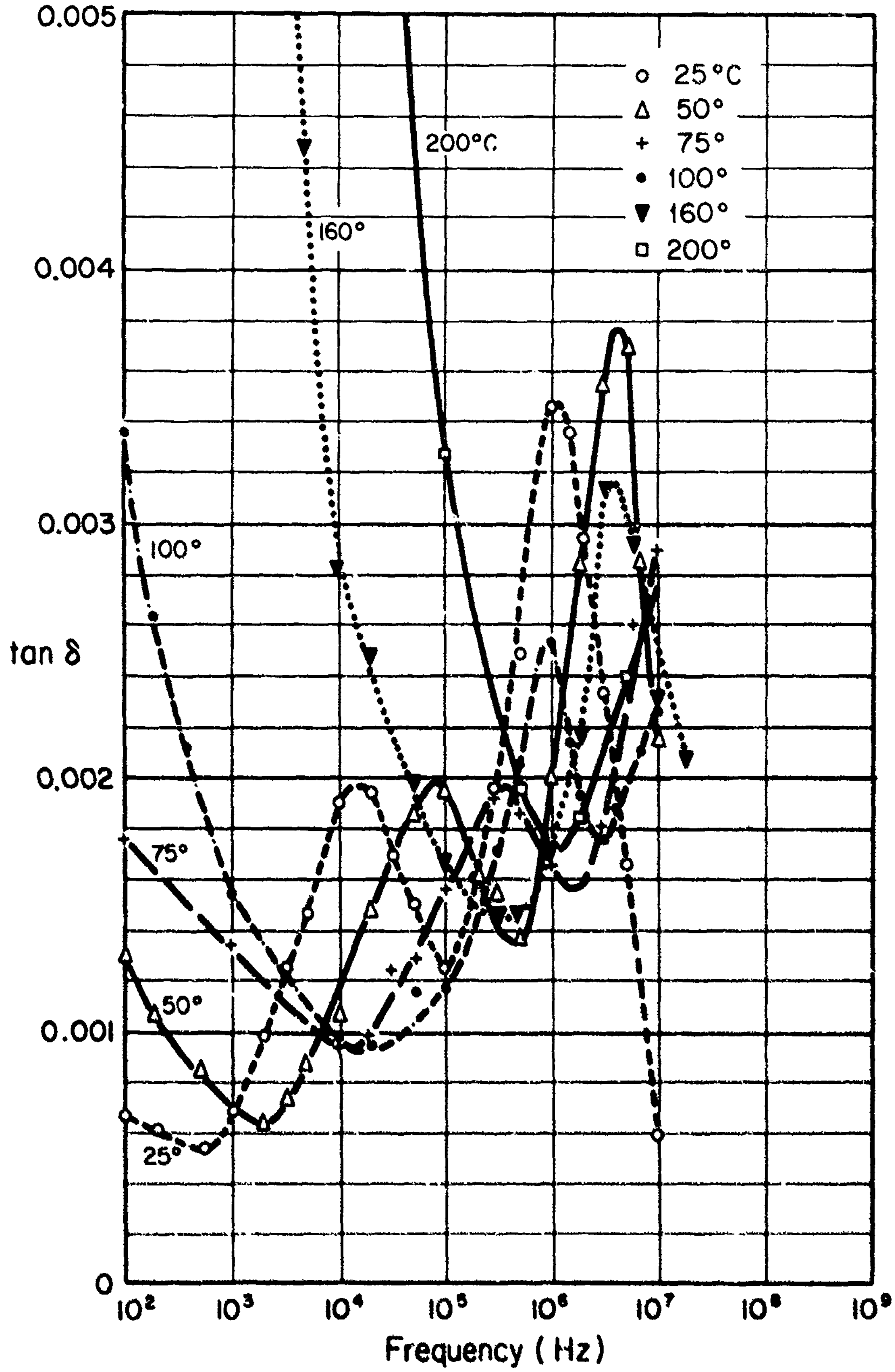
M.I.T., Crystal Physics Laboratory





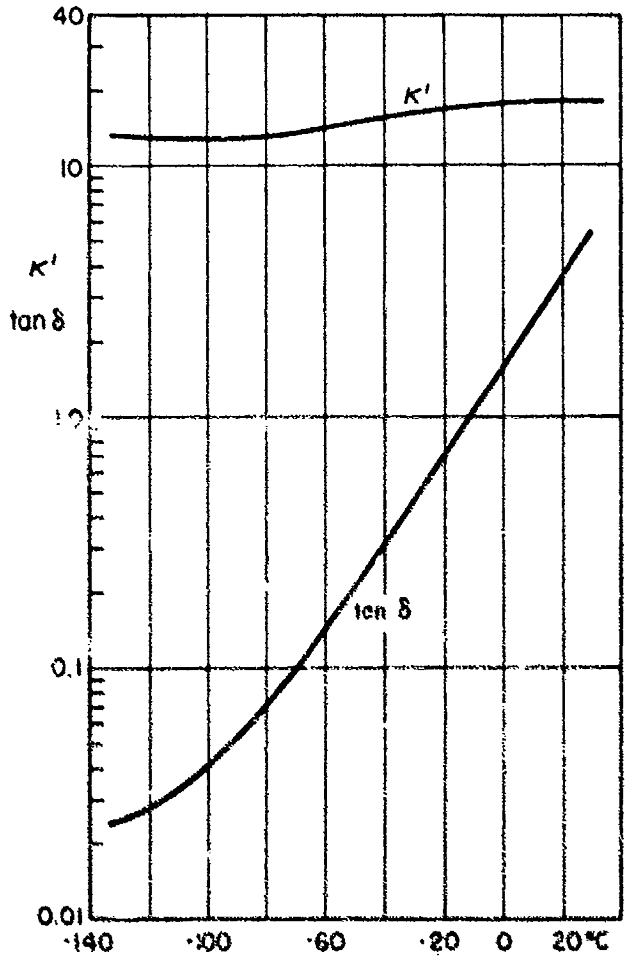


For more complete data see K. V. Rao and A. Smakula, J. Appl. Phys. 37, 319 (1966).


0.005
0.004
0.003
0.002
0.001
0
tan δ
Frequency (Hz)
10²
10³
10⁴
10⁵
10⁶
10⁷
10⁸
10⁹
o 25°C
Δ 50°
+ 75°
• 100°
▼ 160°
□ 200°
200°C
160°
100°
75°
50°
25°

Cerium fluoride, multicrystal, at 1 MHz

M.I.T., Laboratory for Insulation Research

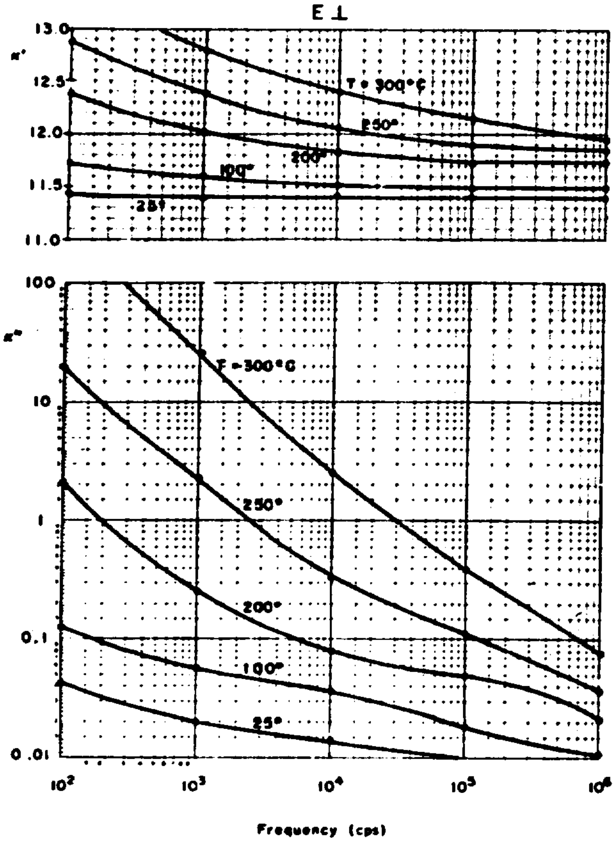


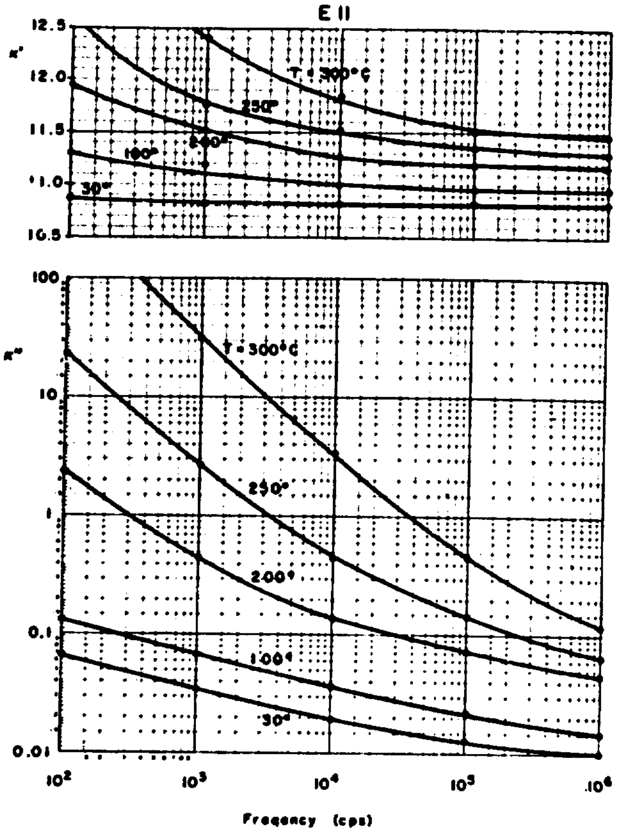
At 25°C

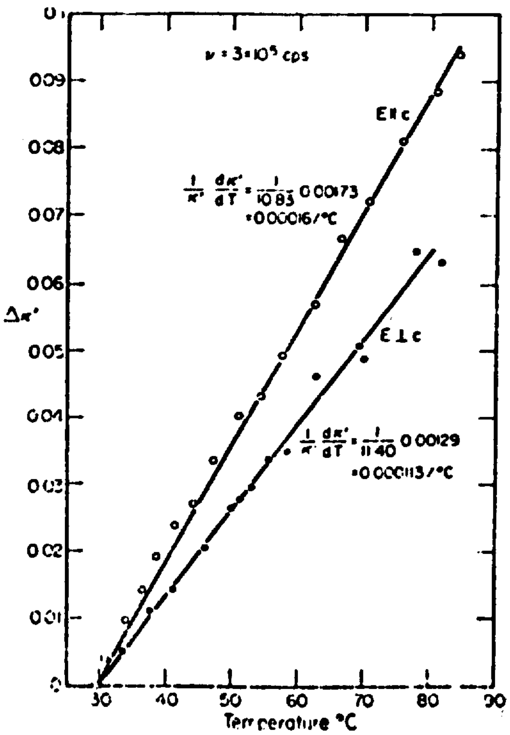
Freq.	10^5	$6x10^7$
κ	2.66	15.8
tan δ	3.86	0.253

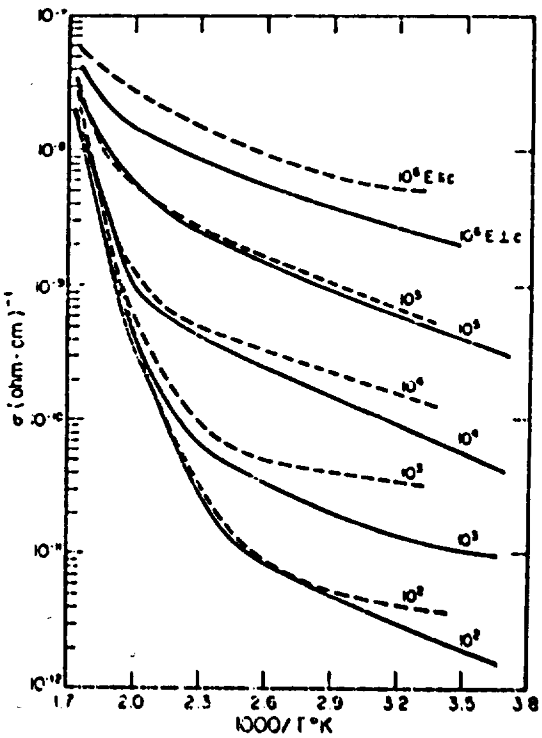
Cr_2O_3 single crystal

The Linde Air Products Company









Cobalt oxide

Massachusetts Institute of Technology
Crystal Physics Laboratory

Cobalt oxide-nickel oxide

At 25°C, 1 MHz

	κ	tan δ
CoO	12.9	.0005
CoO·NiO	40	.39

50/50 mole percent

For complete data see: K. V. Rao and A. Smakula, J. Appl. Phys. 36, 2031 (1965).

Copper halide pressed powders

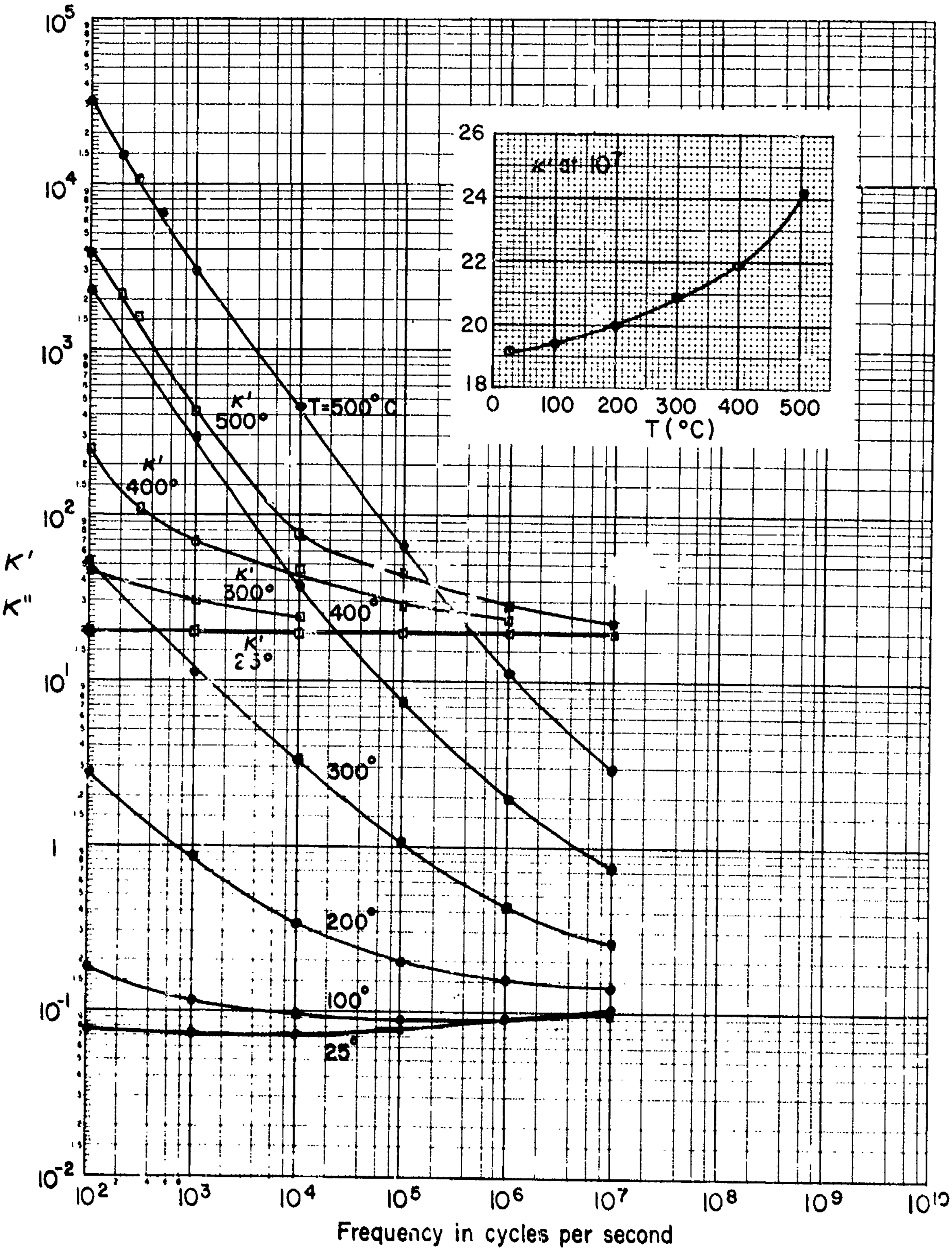
Massachusetts Institute of Technology
Laboratory for Insulation Research

Measured values at 14 GHz

Sample density/X-ray density

	κ'	tan δ
CuBr	4.85/5.17	6.33 < .001
CuCl	3.68/4.10	6.52 < .001
CuI		27.8 < .112

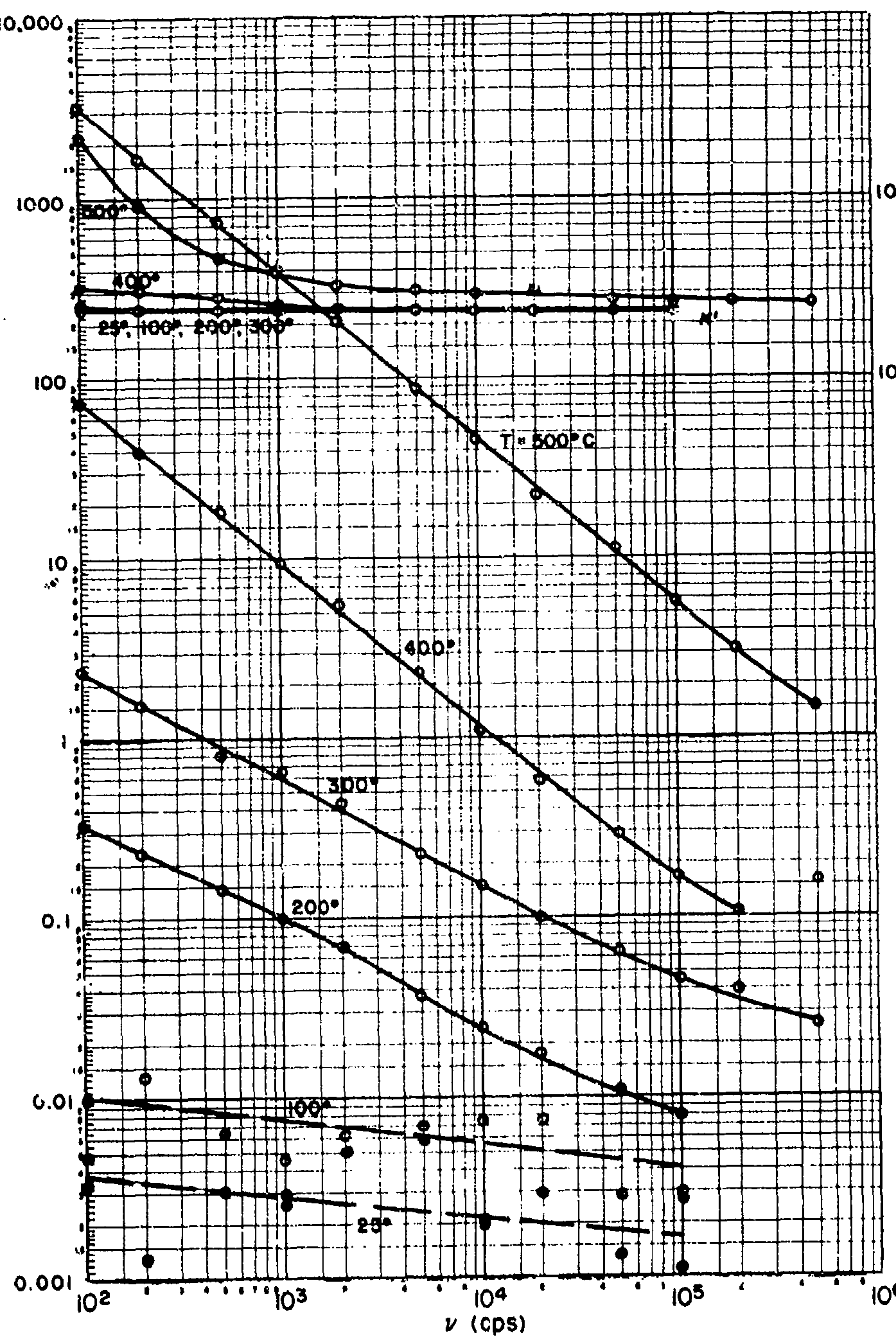
Hafnium oxide (multicrystal) stabilized with Y_2O_3, nuclear grade Zircoa Y-790, density 7.445 g/cm^3 (m.p. 2810°C), see also p. 118

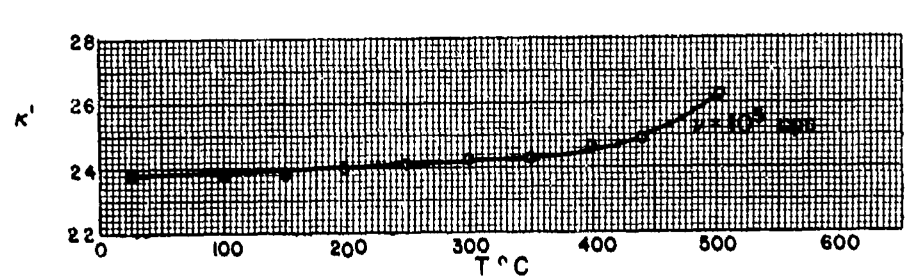


Lanthanum aluminate ($LaAlO_3$),
single crystal (m.p. 1612°C)

National Lead

Elec. field in [111] direction





Lead halides   M. I. T. Crystal Physics Laboratory

	Electric field dir. parallel to		At 1 MHz, 25°C κ'	tan δ	Activation energy for "intrinsic" conduction
$PbBr_2$	a	4.72	52.7	.0052	-
	b	8.06	56.3	.0033	-
	c	9.55	25.3	.0033	-
$PbCl_2$	a	4.53	47.4	.11	.30 eV
	b	7.62	51.3	.065	.28 eV
	c	9.05	24.8	.051	.42 eV
$PbCl_2$-$PbBr_2$ 85/15 mol %	c		28.5	.016	1.1 eV

For additional data on these materials see: A. Smakula, Tech. Rep. No. 6, (Final Report under Contract Nonr 1841(88)), M. I. T., Crystal Phys. Lab., March 11, 1965.

Magnesium aluminate (spinel) $MgOAl_2O_3$

Single crystal   Union Carbide

Density at 25.0°, 3.57389 g/cm^3

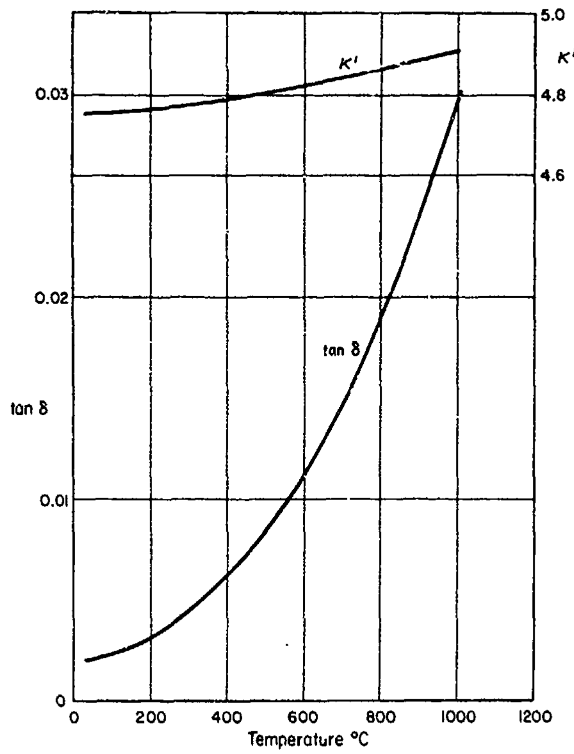
At 8.52, 25°C: κ' = 8.26 ± .04

tan δ = .00009 ± .00002

Freq. 4.23 - 4.07 GHz

T°C	κ ± 02	tan δ
25	8.28	.0001
150	8.42	.0002
231	8.54	.0002
297	8.64	.0003
421	8.85	.0010
455	8.91	.0025

Magnesium aluminum silicate
Cordierite ceramic, at 8.52 GHz
Density 2.44 g/cm^3
Raytheon Company



Magnesium carbonate, hard-packed fine powder, reagent grade, at 8.52 GHz, 25°C:

κ'	tan δ
1.282	.0109

Density .189 g/cm^3

Transparent MgO ceramic
IRTRAN-5

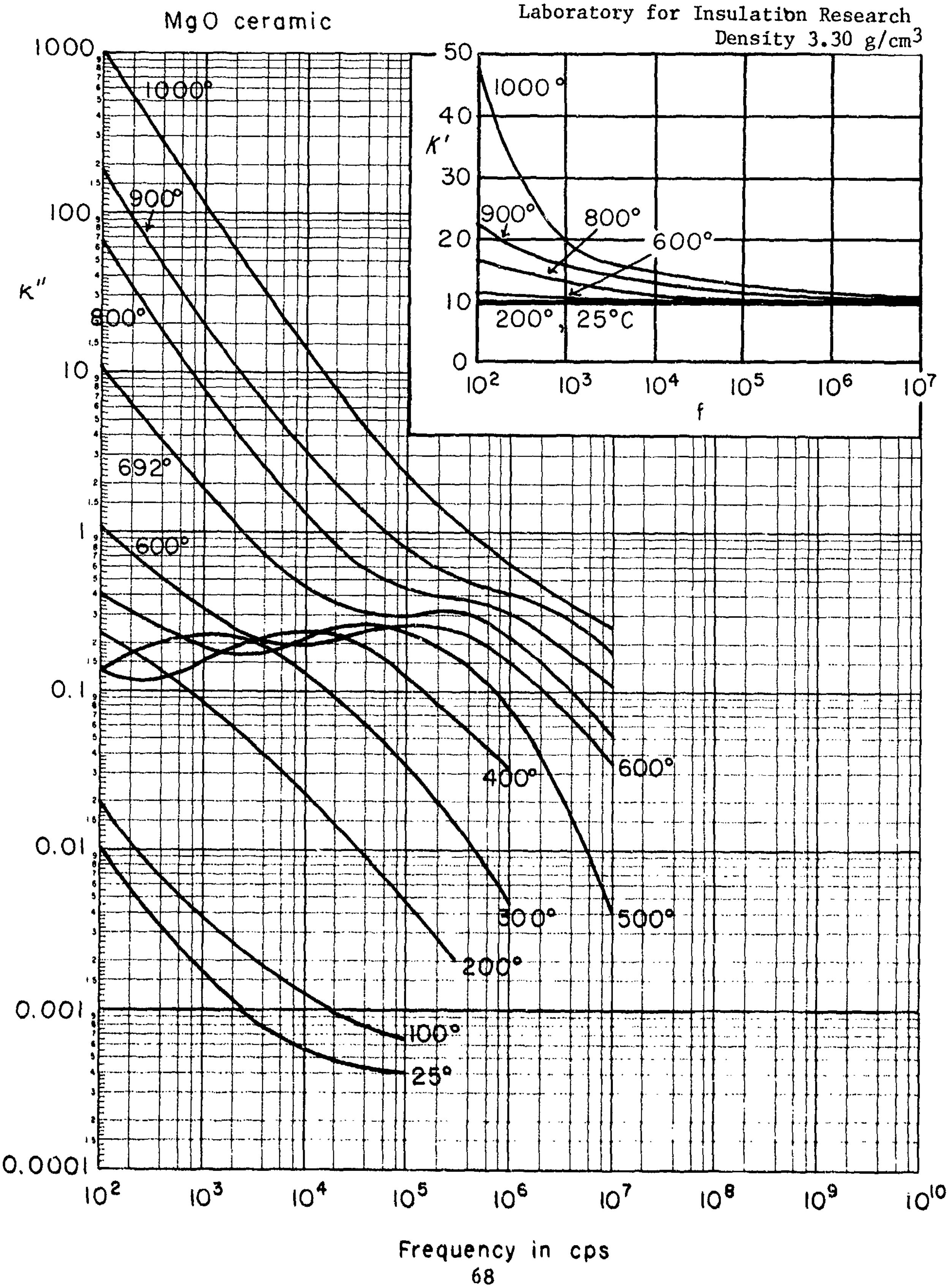
Kodak

Density = 3.57 g/cm^3, 25°C

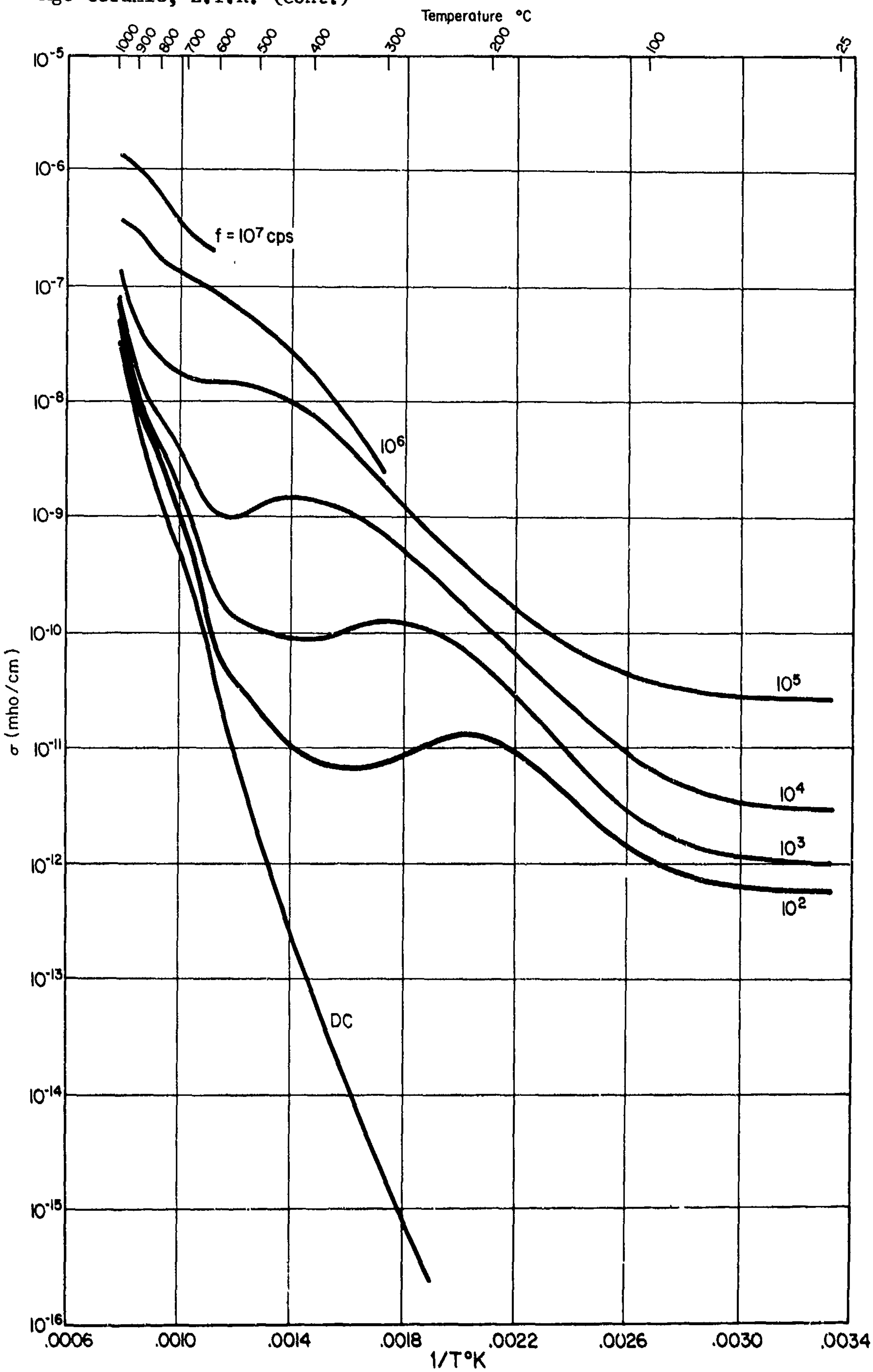
f (Hz)	κ'	tan δ
10^2	9.82	.0014
8.5×10^9	9.72	.00045

Magnesium oxide, single crystal Norton

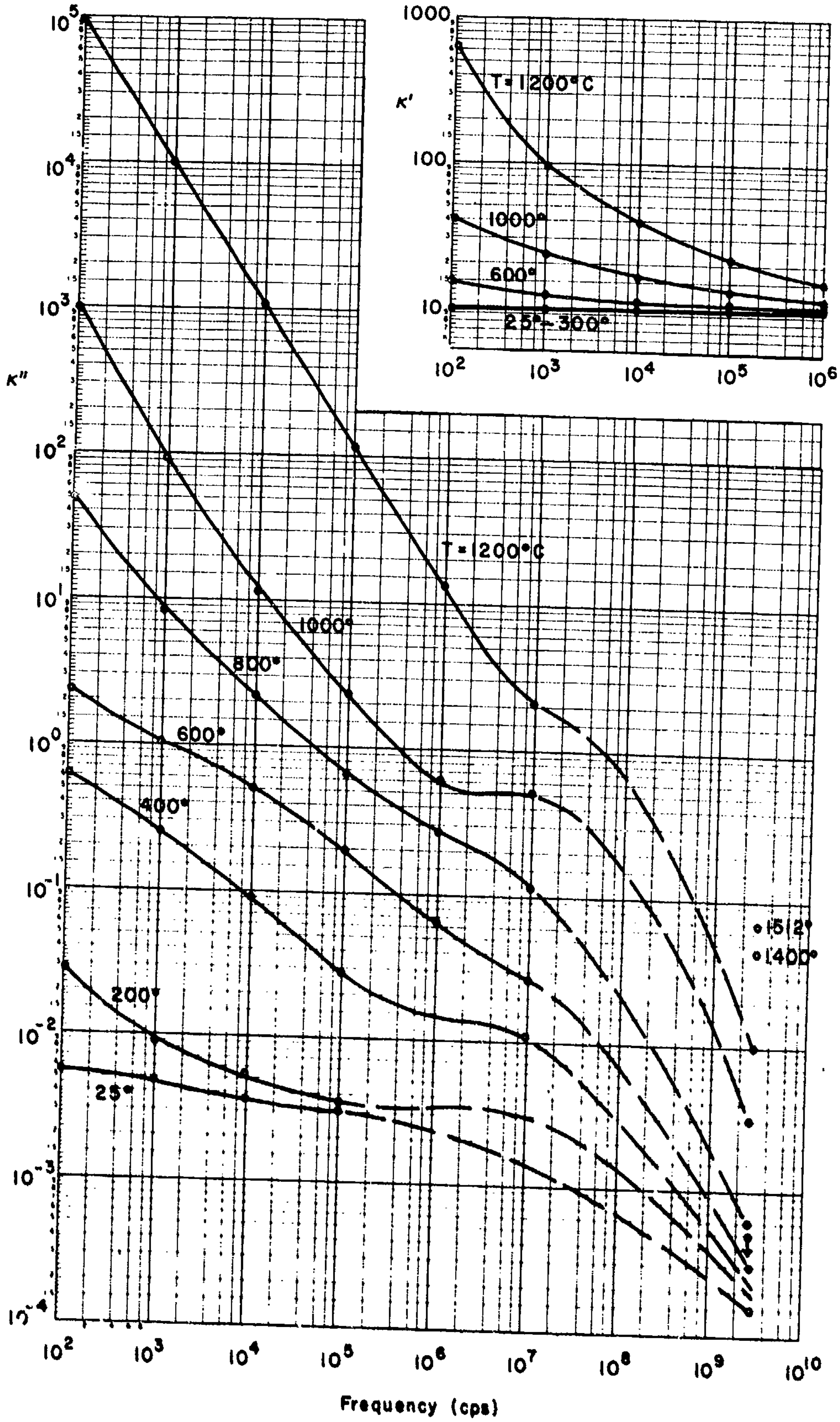
	50 GHz
κ'	tan δ × 10^{-4}
9.72	0.3



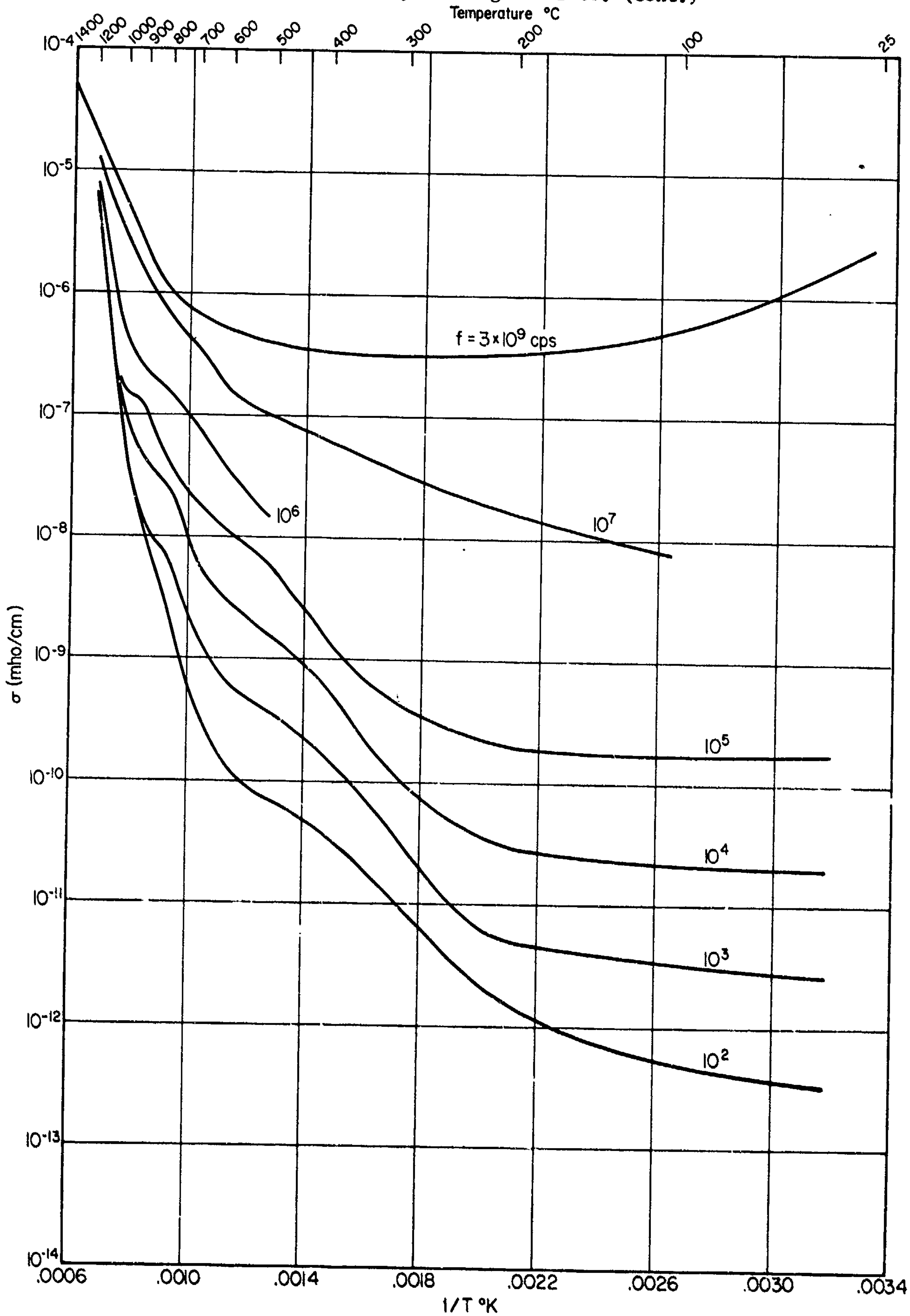
MgO ceramic, L.I.R. (cont.)



MgO ceramic, Minneapolis Honeywell Regulator Co., 99.95% MgO, density 3.52 g/cc.



MgO ceramic, Minneapolis Honeywell Regulator Co. (cont.)



Magnesium metasilicate,
multicrystalline, F-66

Bell Telephone Laboratories

14 GHz

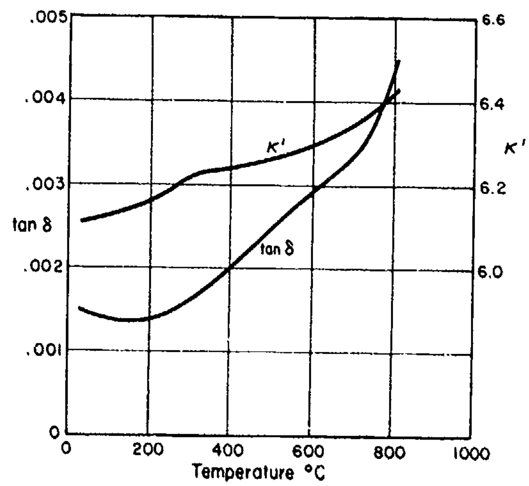
T^oC	κ'	tan δ
25	6.37	.0012
100	6.39	.0012
200	6.43	.0012
300	6.47	.0012
400	6.52	.0013
500	6.58	.0015
600	6.67	.0020
700	6.75	.0047
800	6.85	.0165

50 GHz

25	6.25	.0012

International Pipe and Ceramic Corp.
(Gladding McBean and Co.)

Steatite TC-503, 8.52 GHz



Magnesium orthosilicate, multicrystalline

General Electric
Electronic Components Div.

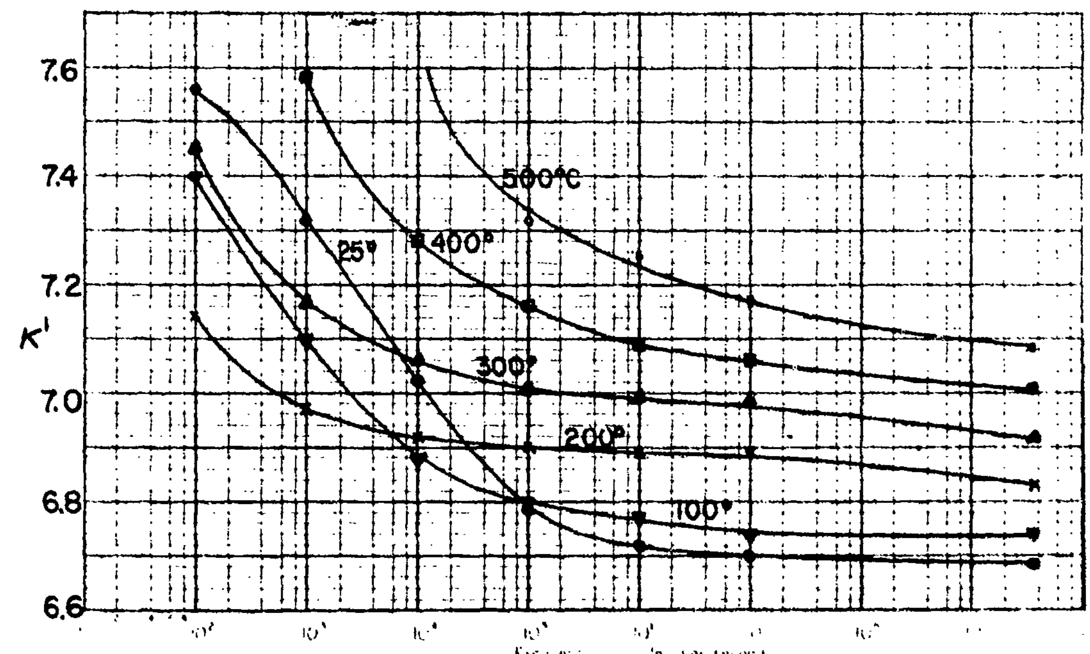
F-118 Density: disk 3.087, cylinder 3.071 g/cm^3

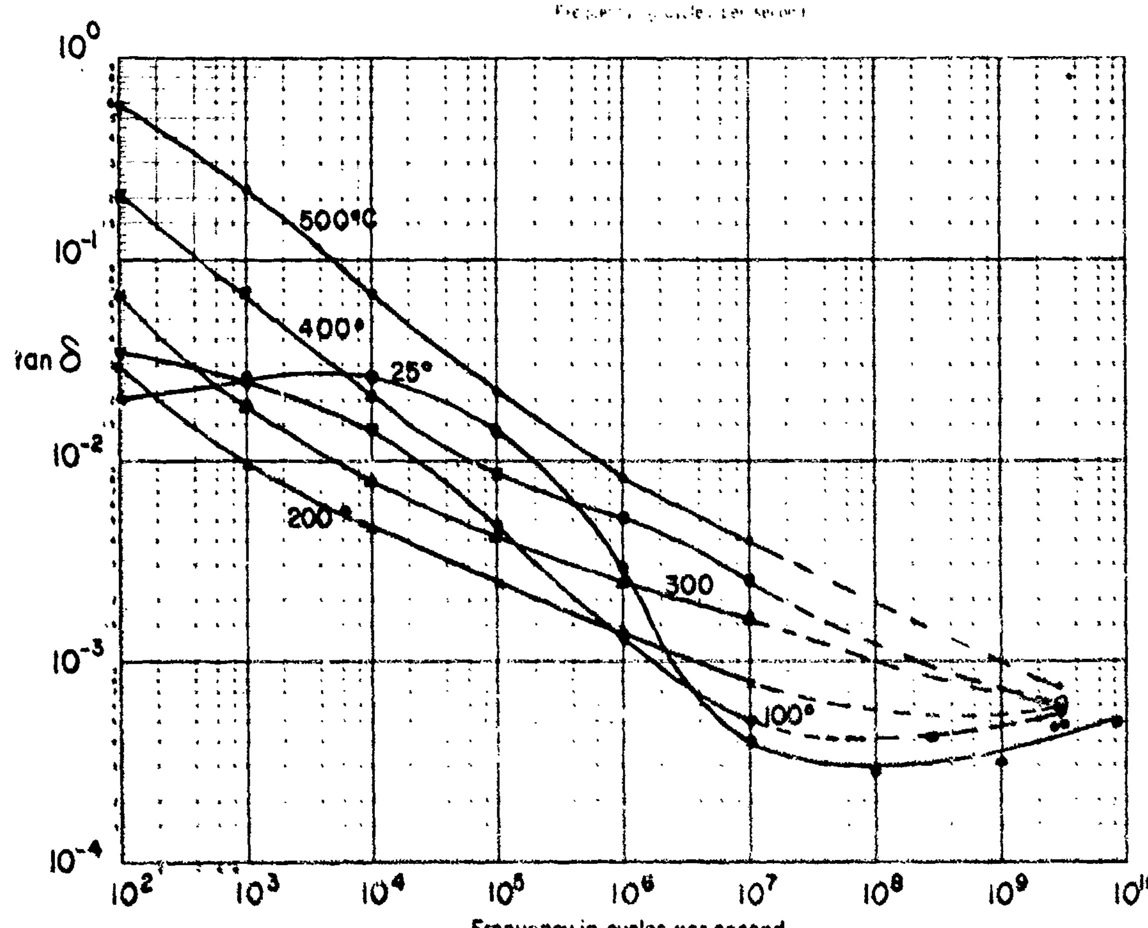
	25°C		100°C		200°C		300°C		400°C		500°C		550°C	
Freq. Hz	κ	tan δ	κ	tan δ	κ	tan δ	κ	tan δ	κ	tan δ	κ	tan δ	κ	tan δ
10^2	6.625	.00098	6.70	.00445	6.80	.00134	6.91	.00636	7.23	.0662	8.78	.421		
10^3	6.62	.00027		.00065	6.79	.00076	6.89	.00198	7.04	.0127	7.44	.0890		
$2x10^3$				.00086										
$3x10^3$				.00098	6.78	.00057								
$4x10^3$				.00108										
$5x10^3$				.00110										
$6x10^3$				.00107										
$8x10^3$				.00102										
10^4	6.62	.00013	6.70	.00090	6.78	.00044	6.88	.00090	6.98	.00334	7.20	.0188		
10^5	6.62	.000110	6.69	.00024	6.78	.00064	6.87	.00051	6.96	.00123	7.14	.0049		
$5x10^5$					6.77	.00098								
10^6	6.62	.000072	6.69	.00016	6.77	.00074	6.85	.00046	6.96	.00069	7.09	.00329		
10^7	6.62	.00011	6.69	.00024	6.77	.00025	6.84	.00083	6.95	.00023	7.08	.00149		
10^8														
$8.5 x10^9$	6.59	.00083	6.64	.00086	6.73	.00092	6.81	.00100	6.90	.00109	6.98	.00119	7.03	.00124
$1.4x10^{10}$														
$2.4x10^{10}$														

F-202

	25°C		100°C		200°C		300°C		400°C		500°C		550°C	
Freq. Hz	κ	tan δ	κ	tan δ	κ	tan δ	κ	tan δ	κ	tan δ	κ	tan δ		
10^2	6.77	.000515	6.86	.00107	6.99	.00[illegible]77	7.26	.02835	9.74	.508	14.73	4.29		
10^3	6.76	.000293	6.85	.00063	6.98	.00202	7.14	.0076	7.70	.142	10.08	.822		
10^4	6.76	.000240	6.84	.00056	6.96	.00124	7.08	.0037	7.34	.0293	8.13	.178		
10^5	6.76	.000233	6.83	.00035	6.95	.00077	7.06	.0017	7.22	.00705	7.40	.0474		
10^6	6.76	.000245	6.83	.00032	6.94	.00067	7.06	.00120	7.18	.0025	7.31	.00975		
10^7	6.76	.00025	6.83	.00025	6.94	.00052	7.05	.00098	7.15	.00153	7.28	.00394		
10^8														
$8.5x10^9$	6.74	.00080	6.81	.00090	6.92	.0015	7.02	.0014	7.13	.0019	7.23	.0027	7.28	.0031
$1.4x10^{10}$														
$2.4x10^{10}$														

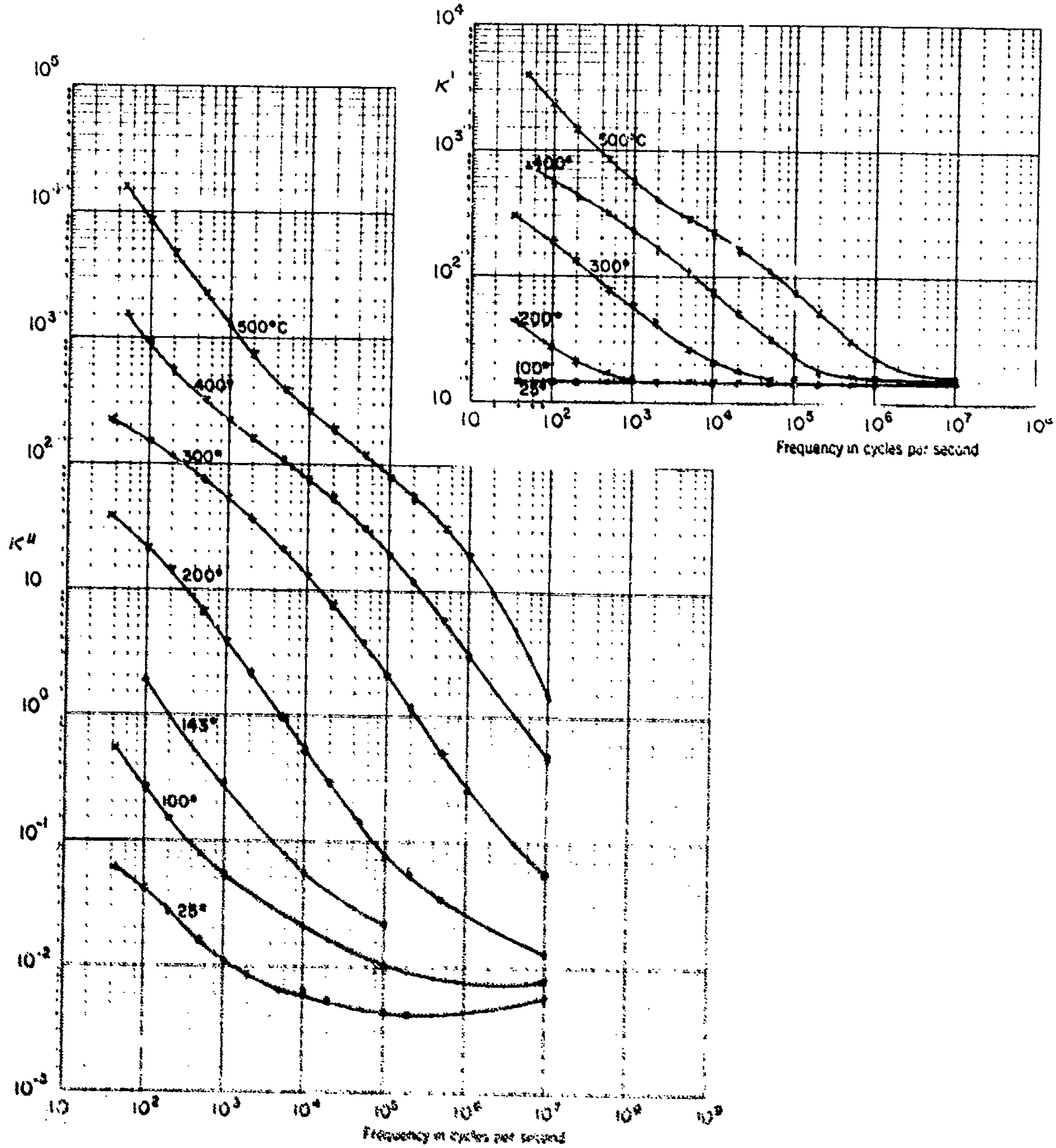
Density of disk 3.087, cylinder 3.086 g/cm^3


7.6
7.4
7.2
7.0
6.8
6.6
K'
500°C
400°
25°
300°
200°
100°


10^0
10^-1
10^-2
10^-3
10^-4
tan δ
500°C
400°
25°
200°
300
100°
10^2
10^3
10^4
10^5
10^6
10^7
10^8
10^9
10^10
Frequency in cycles per second

Magnesium titanate ($MgTiO_3$)
Density 3.21 g/cm^3

U. S. Sonics



Manganese fluoride crystal (MnF_2)

Columbia University

f (Hz)	κ'	tan δ
10^3	7.2 ± .2	.043
10^7	6.7 ± .2	< .004

E ⊥ to platelike, unoriented crystal

Mercury compounds, hot-pressed

Theort. density	Compound	Sample No.	Density (g/cm^3)	T°C		10^2	10^3	10^4	10^5	10^6	10^7	8.5×10^9
6.27	HgI_2	1	-	25	κ		13.7			11.8		13.4
					tan δ		.191			.0034		.0037
		2	5.48	25	κ		14.3			12.57		
					tan δ		.208			.0026		
		3	5.49	25	κ							13.9
					tan δ							< .003
		4	5.56	25	κ	16.11	13.15	12.41	12.39	12.38	12.37	
					tan δ	.828	.154	.0268	.00427	.00117	.00043	
				50	κ	44.35	16.87	13.50	12.98	12.90	12.85	
					tan δ	2.33	.888	.168	.0264	.0047	.00095	
				25	κ	15.45	13.03	12.45	12.42	12.41	12.40	
					tan δ	.713	.185	.0334	.0057	.00149	.00076	
7.15	HgCl	1	5.36	25	κ	7.49	7.48	7.48	7.48	7.46	7.45	
					tan δ	.0013	.00044	.00029	.00034	.00040	.00029	
				50	κ	7.62	7.61	2.59	7.58	7.57	7.57	
					tan δ	.00328	.00095	.0046	.00021	.00028	.00039	
				25	κ	7.58	7.58	7.57	7.57	7.56	7.56	
					tan δ	.00050	.00027	.00018	.00021	.00034	.00046	
7.73	HgS	1	5.19	25	κ	9.75	9.72	9.68	9.64	9.62	9.58	
					tan δ	.0036	.0035	.0029	.0021	.0017	.0011	
				50	κ	9.64	9.61	9.58	9.56	9.53	9.49	
					tan δ	.00324	.00225	.00188	.00174	.00181	.00144	
				25	κ	9.63	9.62	9.62	9.61	9.58	9.57	
					tan δ	.00207	.00177	.00162	.00165	.00147	.00119	

Nickel oxide, NiO, single crystal — M. I. T., Crystal Physics Lab.

At 25°C, 1 MHz

$\kappa' = 11.9$

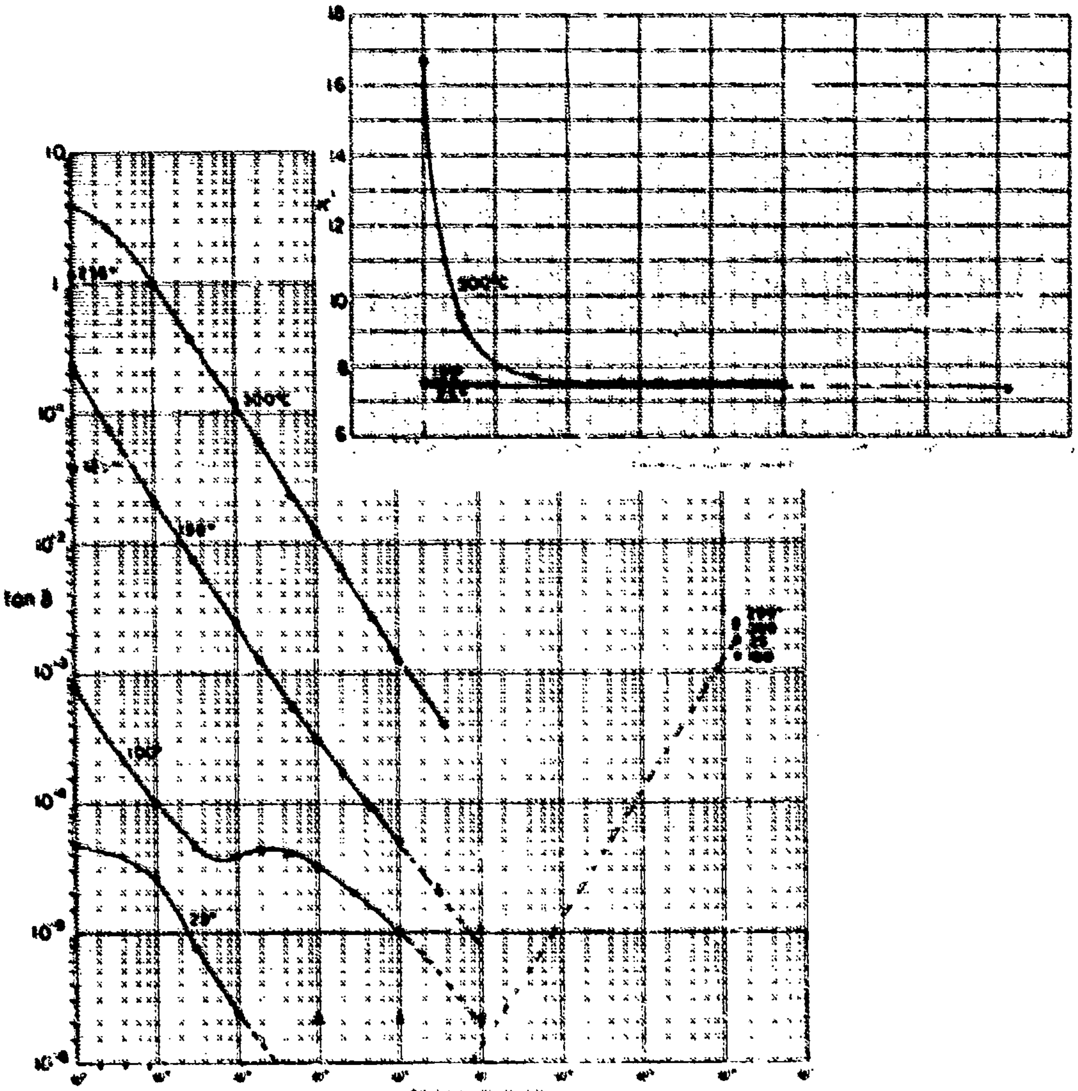
$\tan\delta = .0154$

For complete data see: K. V. Rao and A. Smakula, J. Appl. Phys. 36, 2031-2038 (1965).

Phosphate glass — American Optical

	50 GHz	
	κ'	$\tan\delta \times 10^{-4}$
2043X	5.00	52
2273X	4.74	26

Rubidium manganese fluoride — Massachusetts Institute of Technology Crystal Physics Laboratory

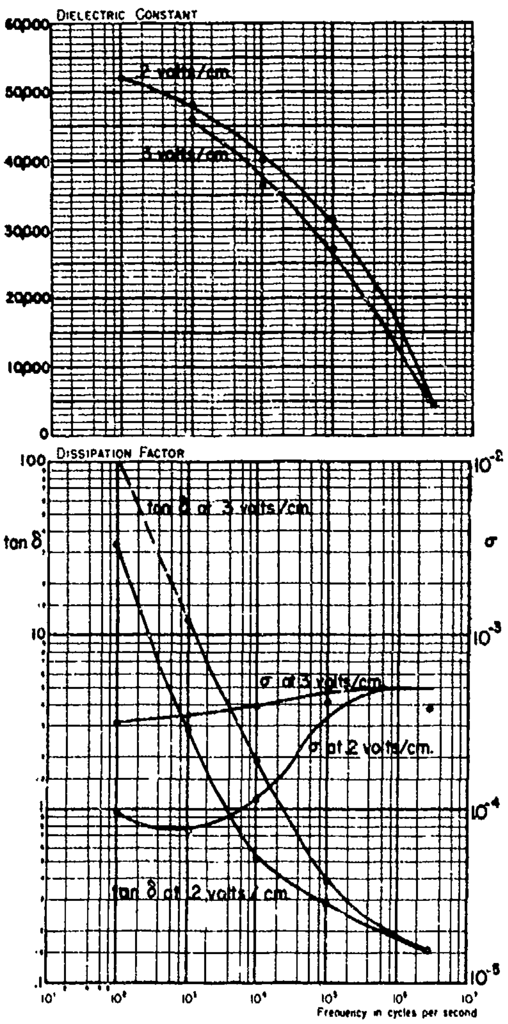


Silicon crystal, undoped

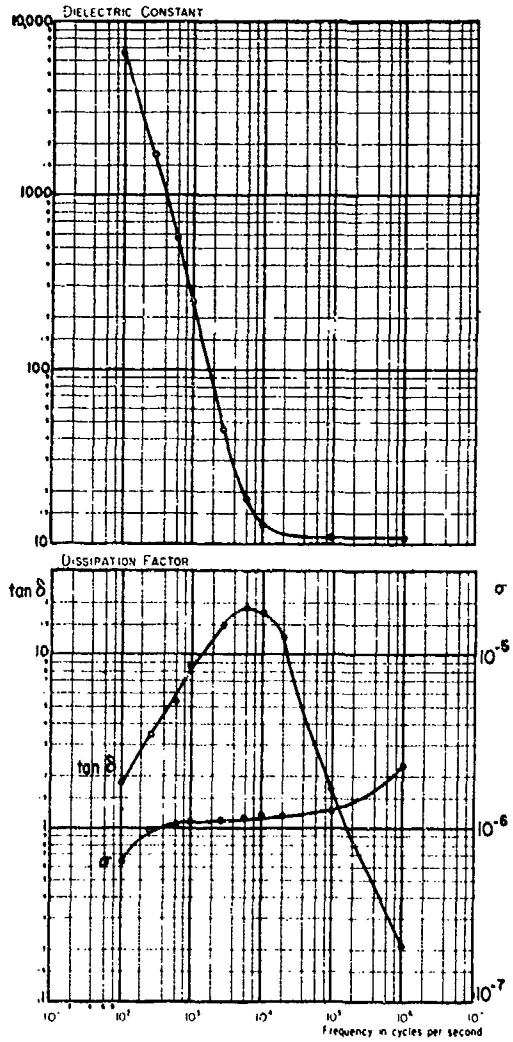
Brown University

Apparent properties of 1 cm cube sample with evaporated gold electrodes.

Silicon single crystal



Radiation damaged single crystal



Silicon crystal, intrinsic

M. I. T., Crystal Physics Lab.

at 25°C

f (Hz)	κ'	tan δ	ρ (ohm-cm)
10^3	-	-	4100
1.4×10^{10}	12.0	.0090	1190

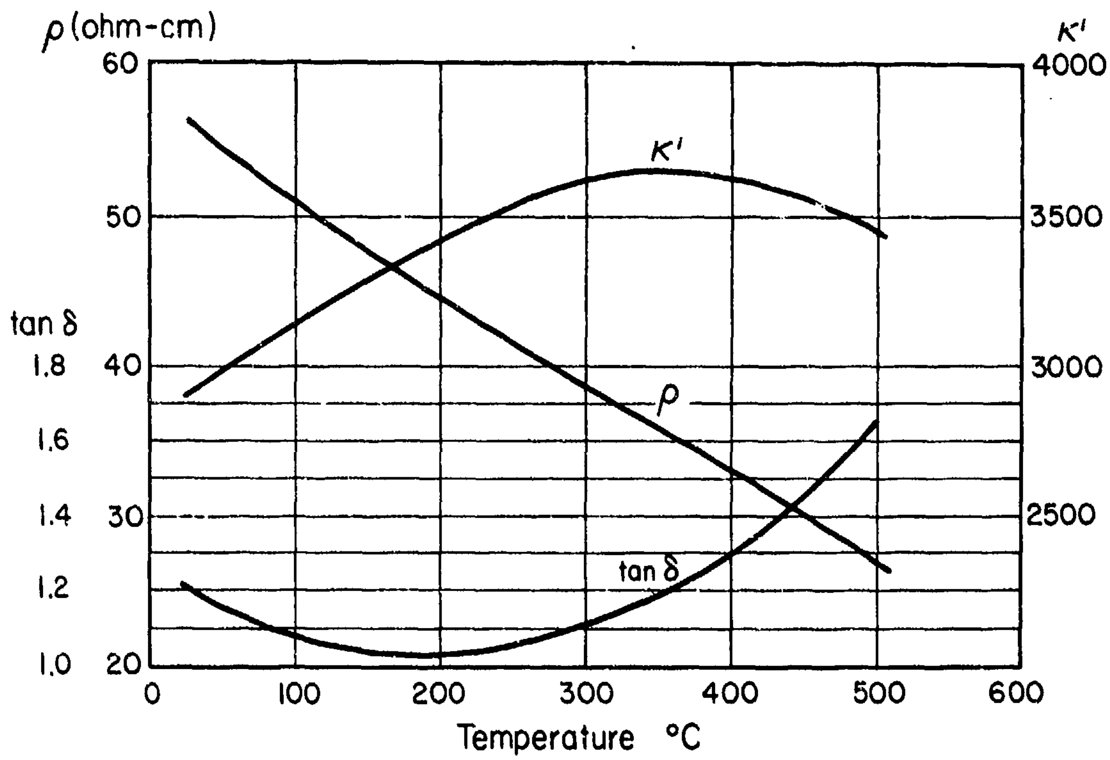
Silicon carbide type attenuator materials Carborundum

Nominal resistivity (ohm-cm)	Temperature (^{o}C)	f (Hz)	κ'	tan δ	Measured resistivity (ohm-cm)
35	25	3×10^{8}	167	0.96	37.2
	25	10^{9}	107	0.686	24.4
	25	3×10^{9}	60	0.58	17.2
	25	8.5×10^{9}	47.7	0.55	8.05
0.1	25	8.5×10^{9}	2130	1.85	0.069
50	25*	10^{6}	10,150	1.17	151
	25**	10^{6}	29,450	1.36	45
	25*	10^{7}	2810	1.21	56.5

* Two-terminal measurement.

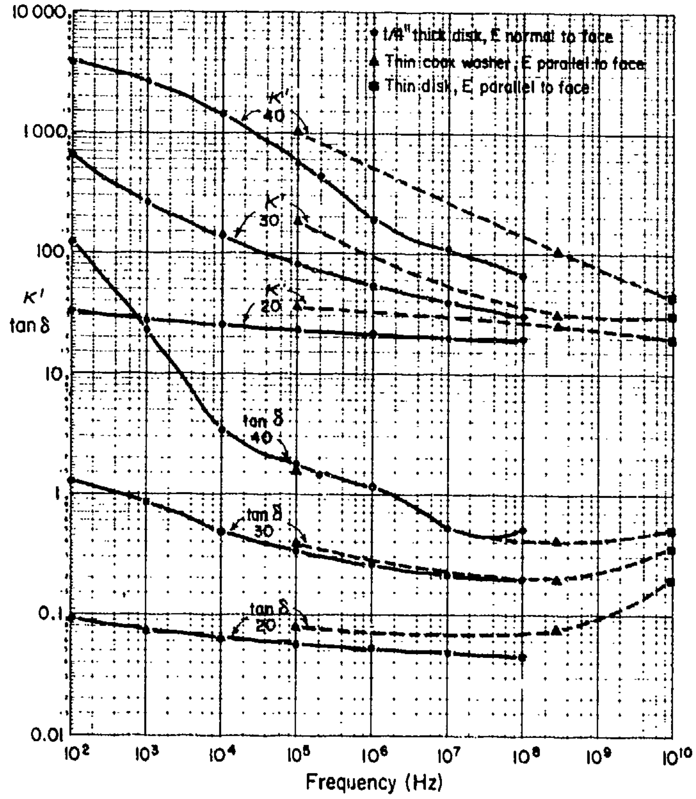
** Four-terminal measurement, different sample

Nominal 50-ohm material at 10^7 Hz



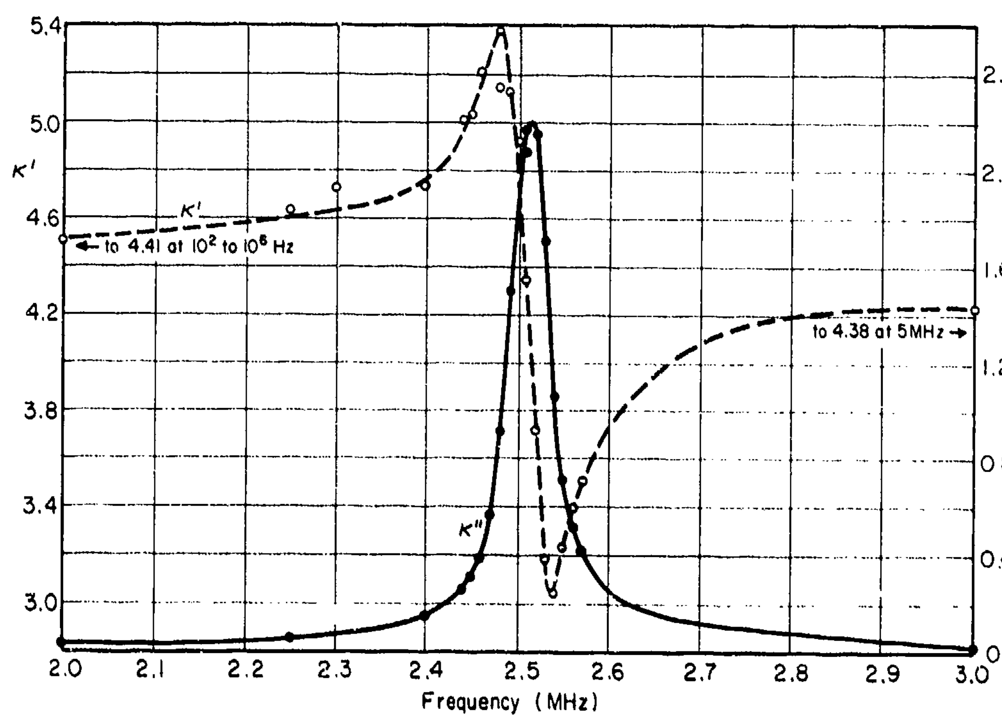
Carberlox 20, 30, 40
BeO and silicon carbide ceramic

National Beryllia Corp.



Silicon dioxide, natural quartz crystal,
Y-cut plate, silver paint electrodes, at 25°C

Fort Monmouth



Quartz, continued

Y-cut plate

At 25°C, $\kappa' = 4.40$

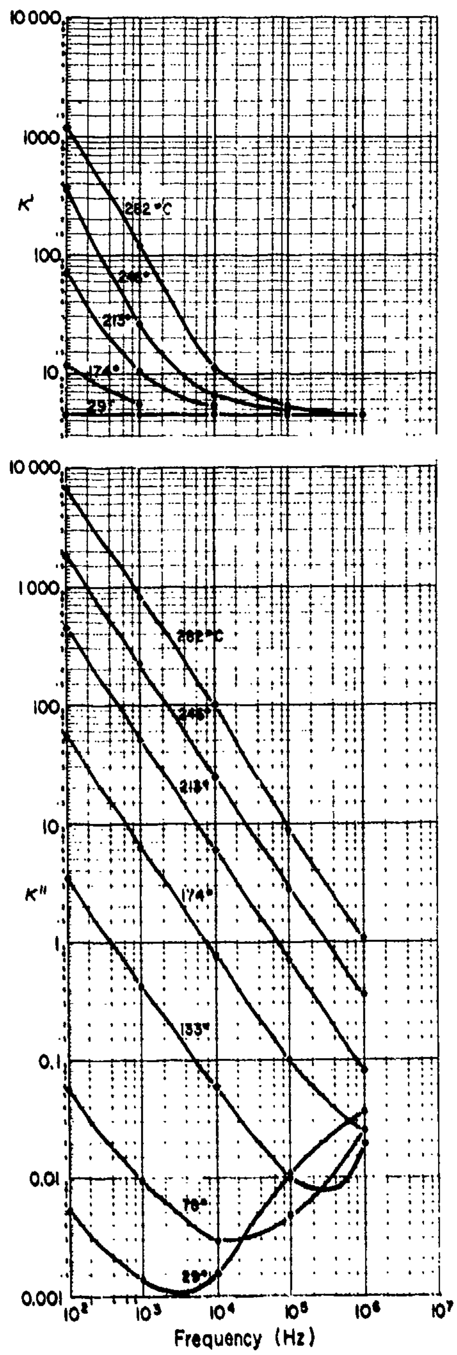
$1/\kappa'\left(\frac{d\kappa'}{dt}\right) = -2.8 \times 10^{-5}/^{\circ}C$

Z-cut plate, E || optic axis

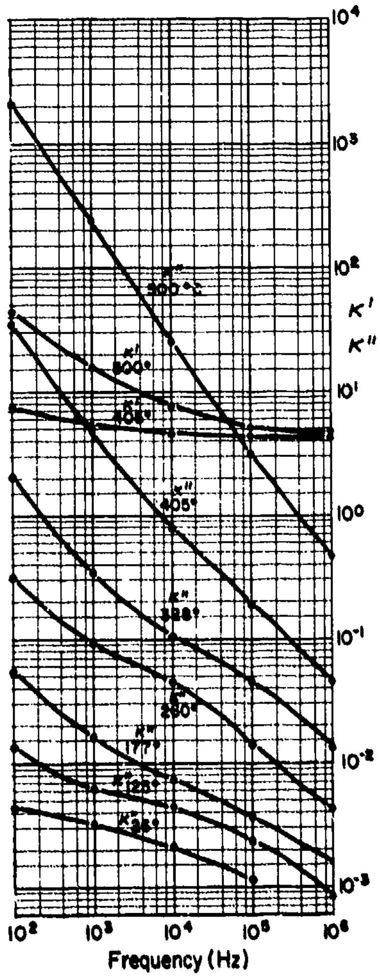
At 25°C, $\kappa' = 4.64$

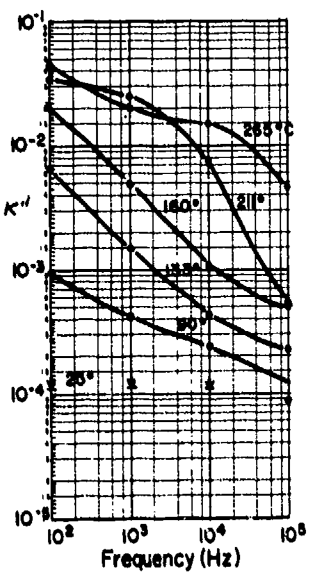
$1/\kappa'\left(\frac{d\kappa'}{dt}\right) = -3.9 \times 10^{-5}/^{\circ}C$

Silver electrodes

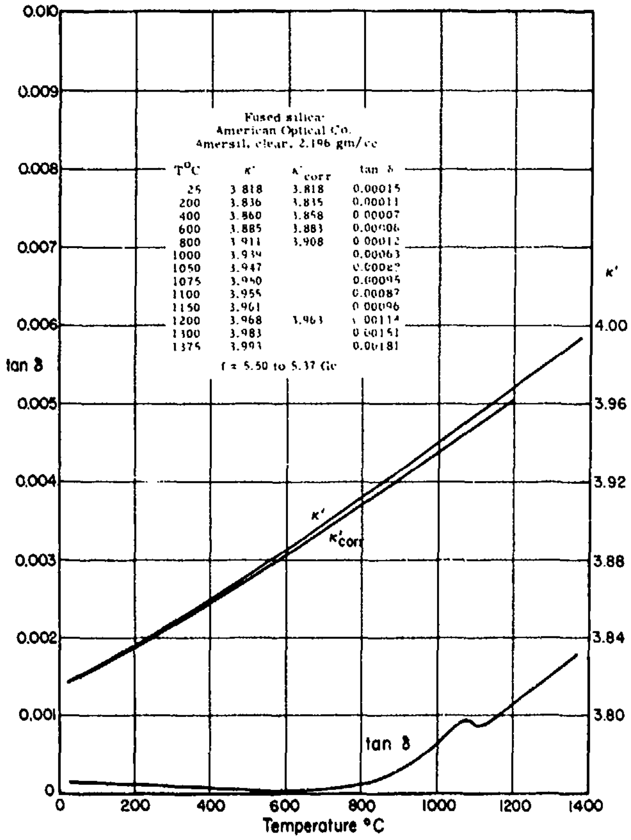


Pt electrodes

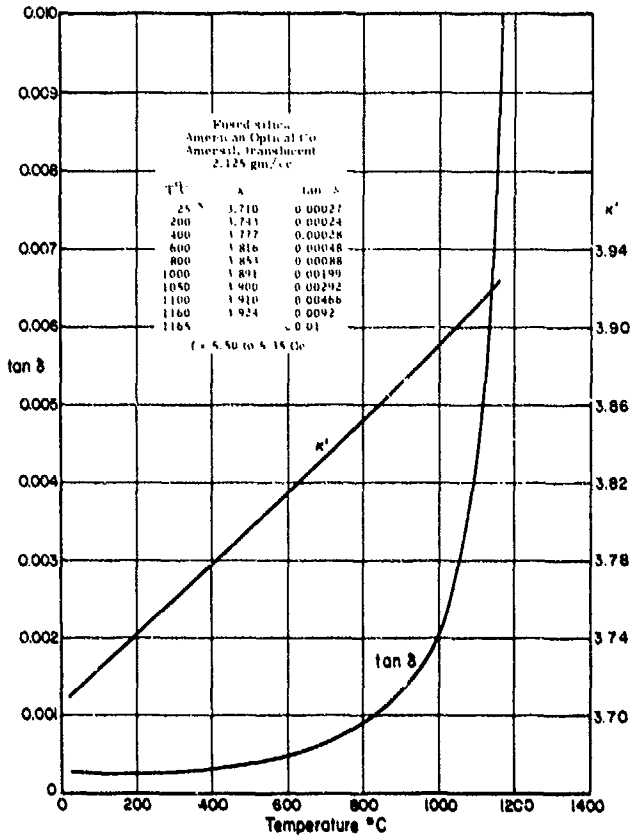




Silicon dioxide
Glasses



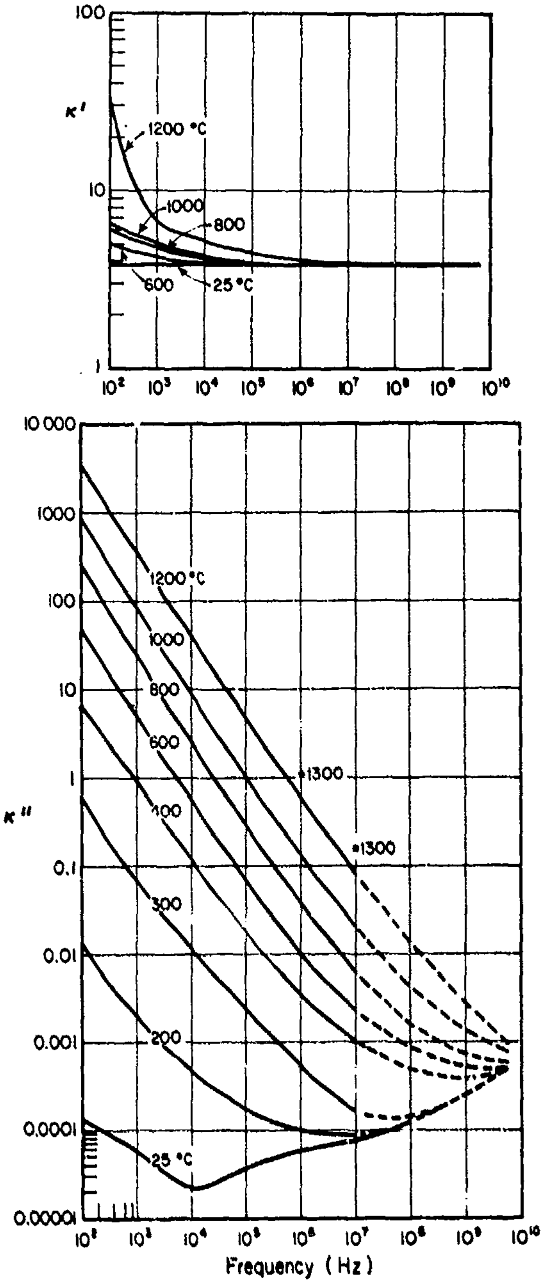
T°C	κ'	κ'corr	tan δ
25	3.818	3.818	0.00015
200	3.836	3.835	0.00011
400	3.860	3.858	0.00007
600	3.885	3.883	0.00006
800	3.911	3.908	0.00012
1000	3.939		0.00063
1050	3.947		0.00082
1075	3.950		0.00095
1100	3.955		0.00087
1150	3.961		0.00096
1200	3.968	3.963	0.00114
1300	3.983		0.00151
1375	3.993		0.00181



T°C	κ'	tan δ
25	3.710	0.00027
200	3.743	0.00024
400	3.777	0.00028
600	3.816	0.00048
800	3.853	0.00088
1000	3.891	0.00199
1050	3.900	0.00292
1100	3.910	0.00466
1160	3.924	0.0092
1165		~0.01

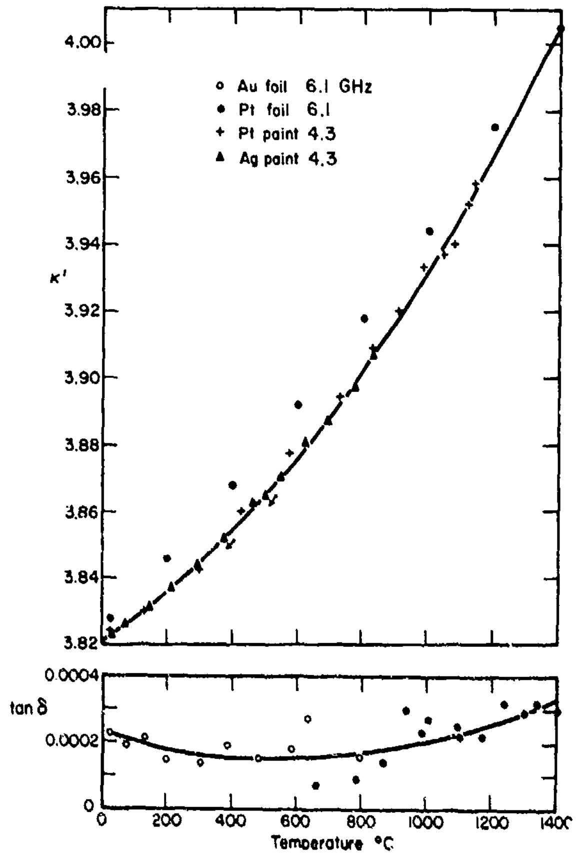
Silicate glasses

Fused silica, Corning 7940

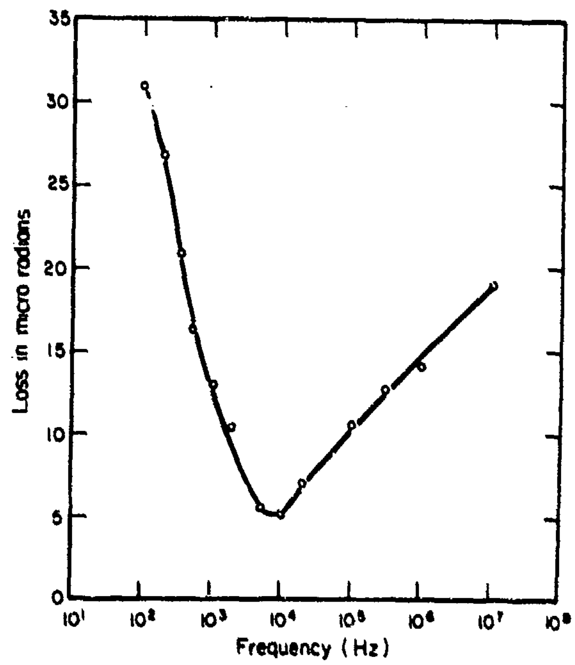


Corning Glass Works

Microwave data on fused silica, Corning 7940, density = 2.20027 g/cm^3. Data with foil taken on one sample at 6.1 GHz, data with paint taken on second sample at 4.3 GHz.



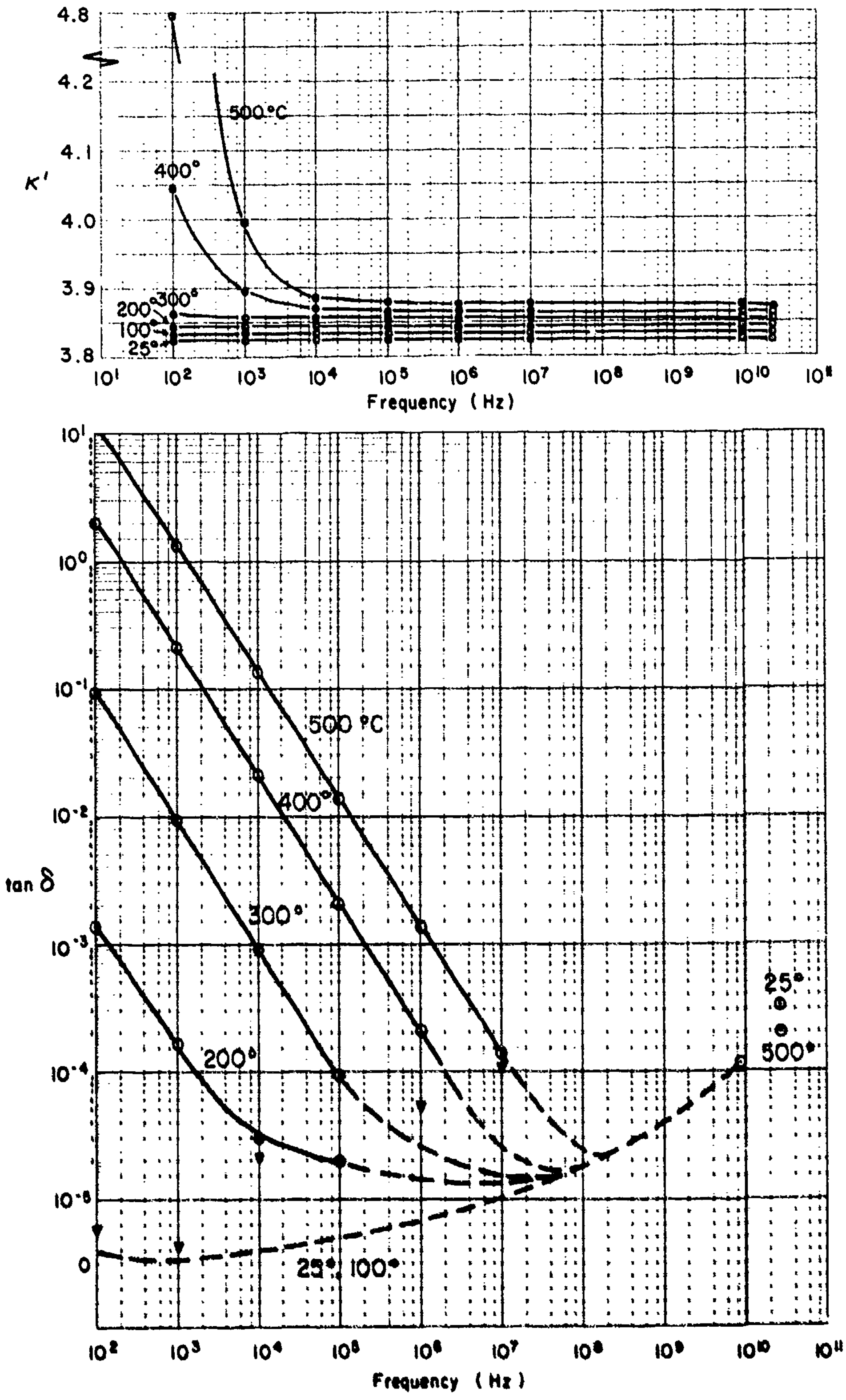
Corning 7940 continued



Silicon dioxide, high purity glasses

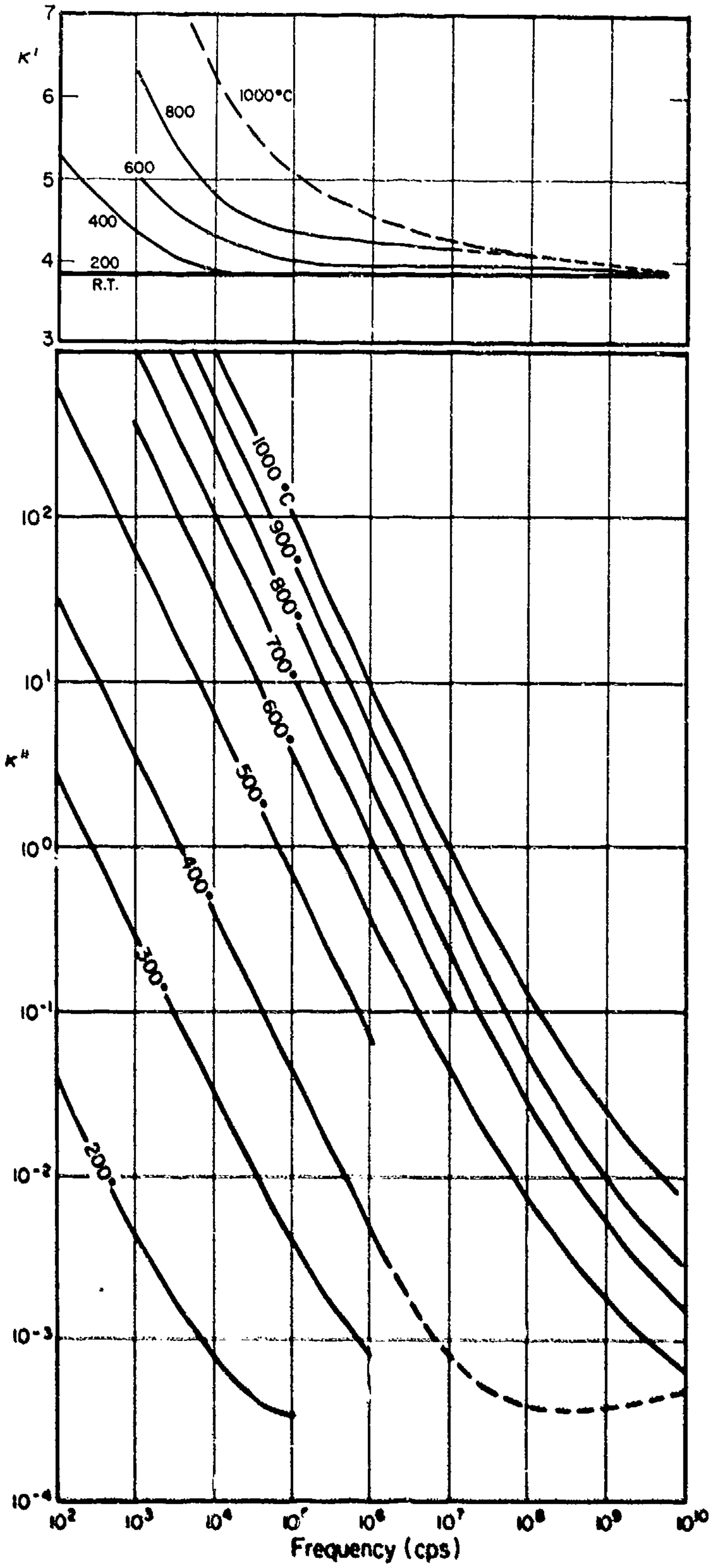
Dynasil 4000

Dynasil Corporation of America
Berlin, New Jersey 08009



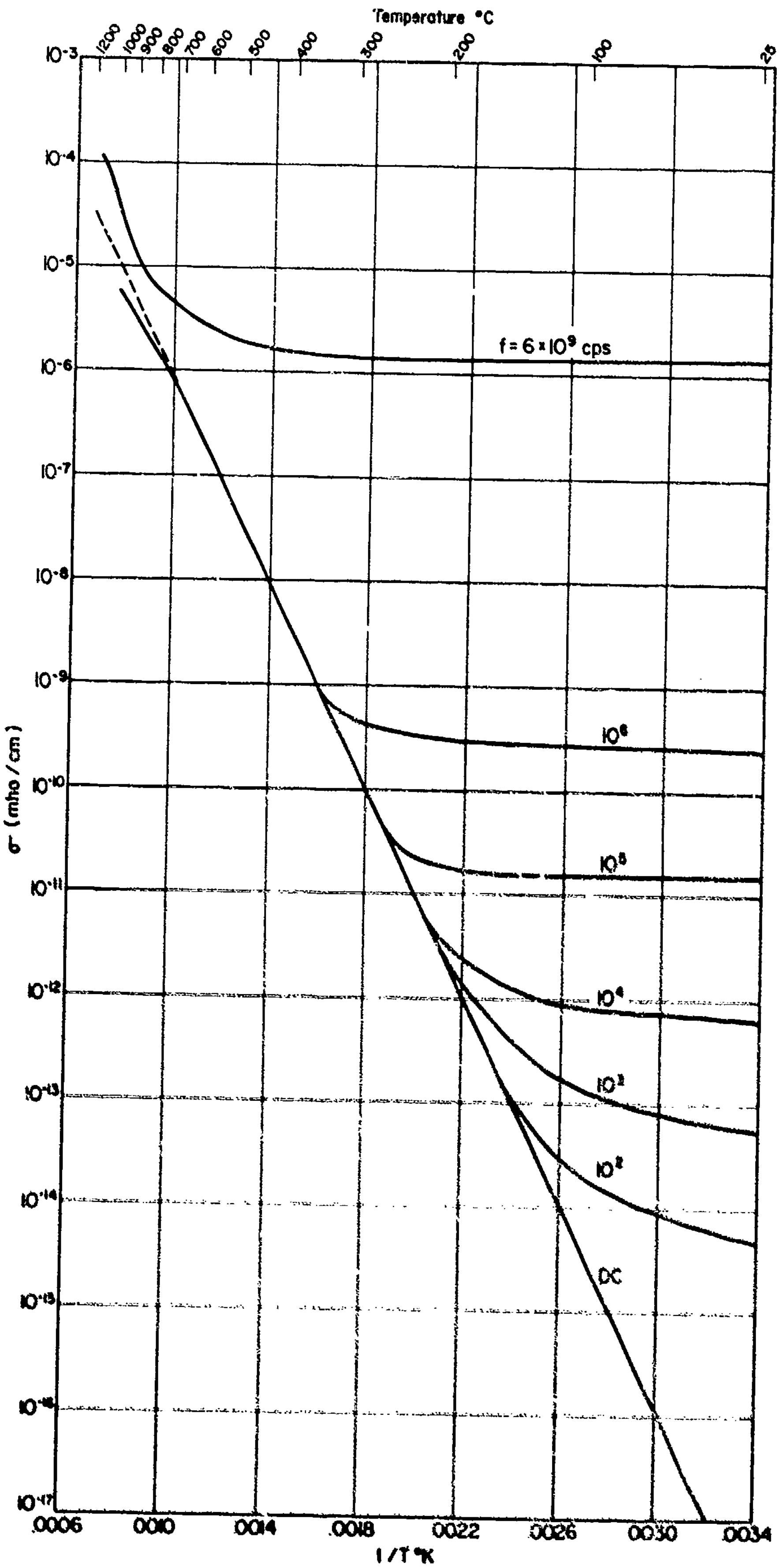
SiO_2, glass, Type 101 clear, fused quartz, 99.97 to 99.98% SiO_2

General Electric Silicon dioxide Dept.

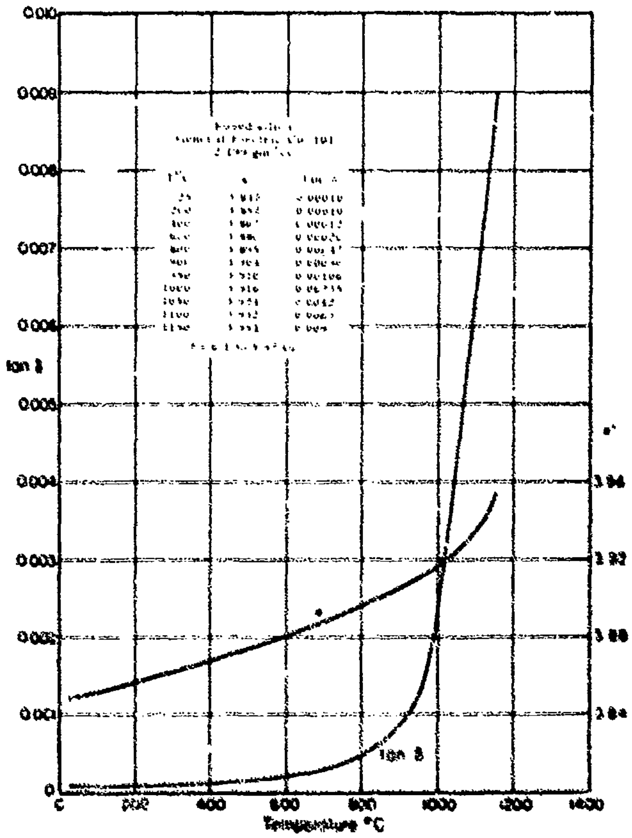


At 50 GHz, 25°C, κ' = 3.80, tan δ = 0.0002

SiO_2, glass (cont.)



Silicon dioxide (cont.)



Silicon dioxide, high-purity glasses (cont.)

Spectrosil A

Thermal American Fused Quartz Co.
Montville, N.J. 07045

25°C, 8.52 GHz: $\kappa' = 3.826 \pm .003$

$10^4 \tan\delta = 1.9 \pm .4$

Spectrosil B

25°, 8.52 GHz: $\kappa' = 3.825 \pm .003$

$10^4 \tan\delta = 1.5 \pm .2$

T°C		Frequency in Hz 10^2	10^3	10^4	10^5	10^6	10^7
25	κ	3.823	3.823	3.823	3.823	3.823	3.823
	$10^6 \tan\delta$	<4	<4	6	7	<40	<130
100	κ	3.83	3.83	3.83	3.83	3.83	3.83
	$10^6 \tan\delta$	<4	<4	<8	<10	<40	<130
197	κ	3.84	3.84	3.84	3.84	3.84	3.84
	$10^6 \tan\delta$	264	44	15	<20	<40	<130
300	κ	3.86	3.86	3.86	3.86	3.86	3.86
	$10^4 \tan\delta$	151	15.9	2	<.4	<.6	<1.3
398	κ	3.89	3.86	3.86	3.86	3.86	3.86
	$10^2 \tan\delta$	15.9	1.76	.219	.04	<.02	<.02
486	κ	3.98	3.89	3.87	3.87	3.87	3.87
	$\tan\delta$	.79	.0883	.00954	.0015	.0005	.0002

Vitreosil, optical grade

25°C, 8.52 GHz, $\kappa' = 3.811 \pm .005$; $10^4 \tan\delta = 1.17 \pm .2$

Vitreosil, commercial grade

25°C, 8.52 GHz, $\kappa' = 3.805 \pm .01$; $10^4 \tan\delta = .80 \pm .13$

Mixed silicate glasses

Corning Lab. No. 119BUC magnetic glass — Corning Glass Works

25°C, 8.52 GHz

κ'	tan δ	κ'_m	tan δ_m
20.8	0.157	1.006	0.372

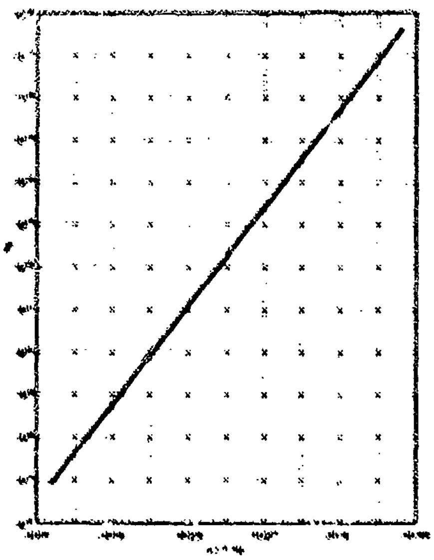
Corning Code 1723 glass

14 GHz			24 GHz		
T°C	κ'	tan δ	T°C	κ'	tan δ
25	6.18	.0069	25	6.13	.0075
85	6.21	.0067	85	6.16	.0075
144	6.24	.0065	155	6.20	.0074
231	6.27	.0063	251	6.24	.0073
305	6.31	.0061	333	6.28	.0074
339	6.33	.0060	419	6.32	.0073
396	6.36	.0059	446	6.35	.0073
464	6.40	.0057	510	6.39	.0074
502	6.43	.0056			

Lancaster

No. 7552

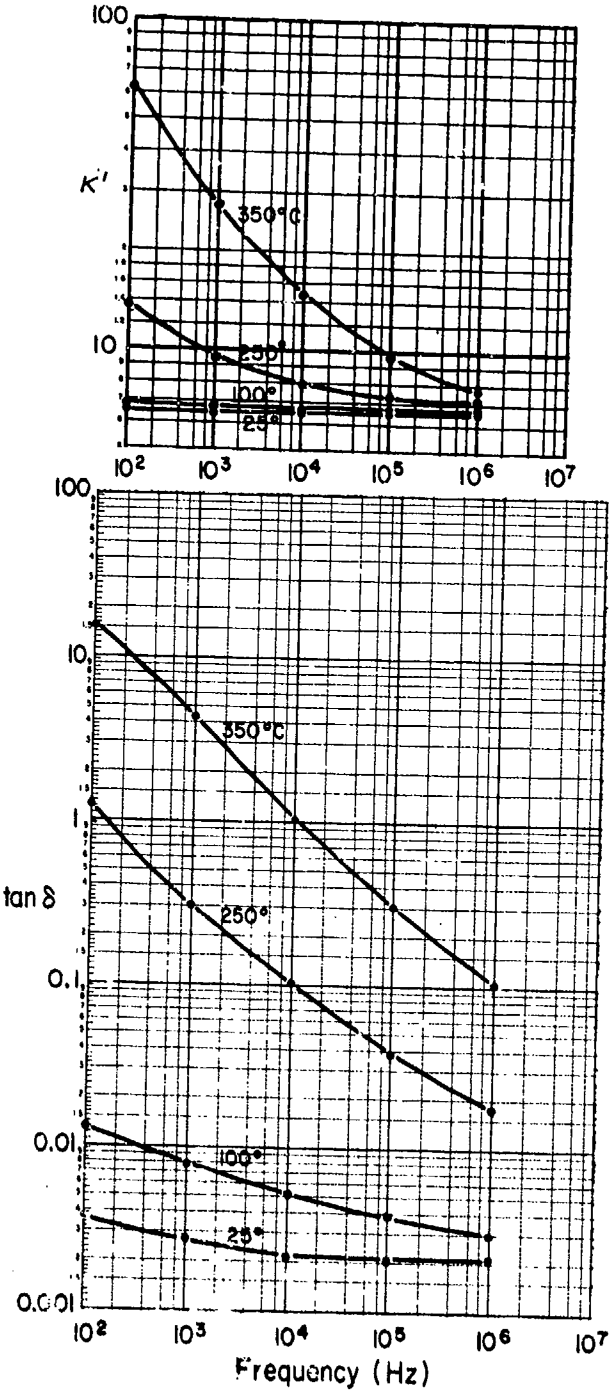
Resistivities measured at 100 Hz



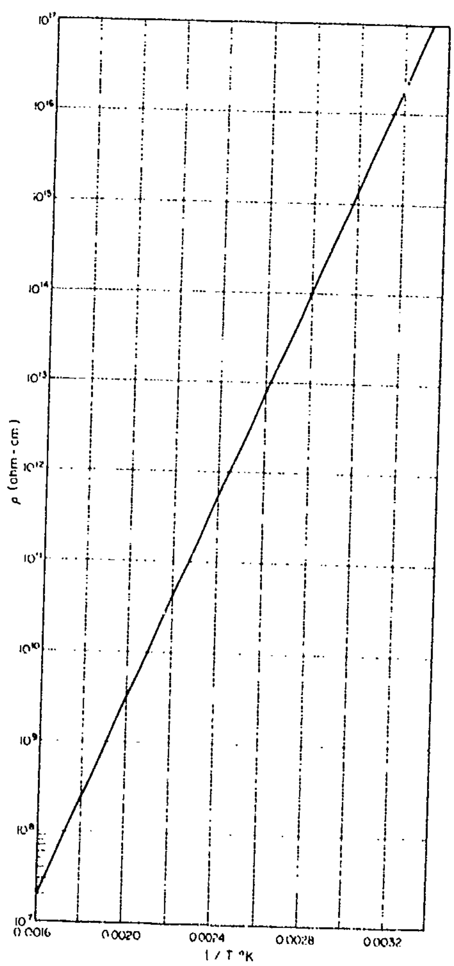
Silica glasses (cont.) Lancaster

(Mixed silicate glasses), resistivities measured at 100 Hz

7357

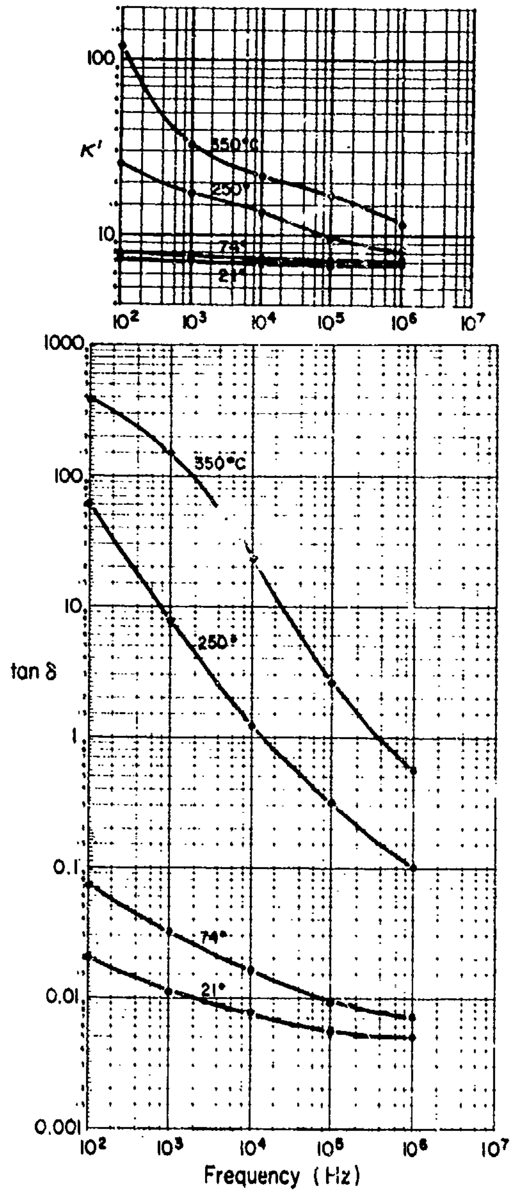


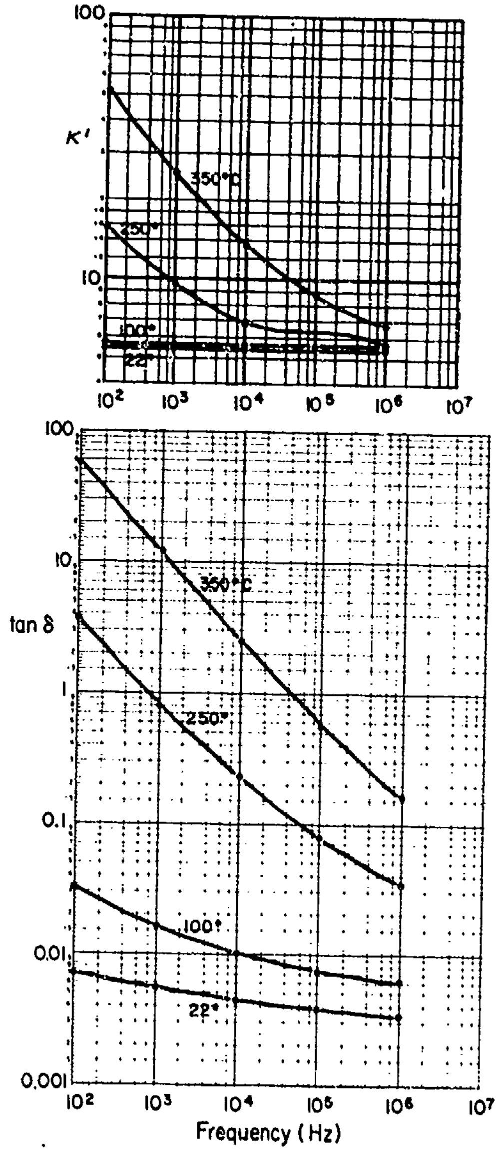
7357



Lancaster glasses (cont.)

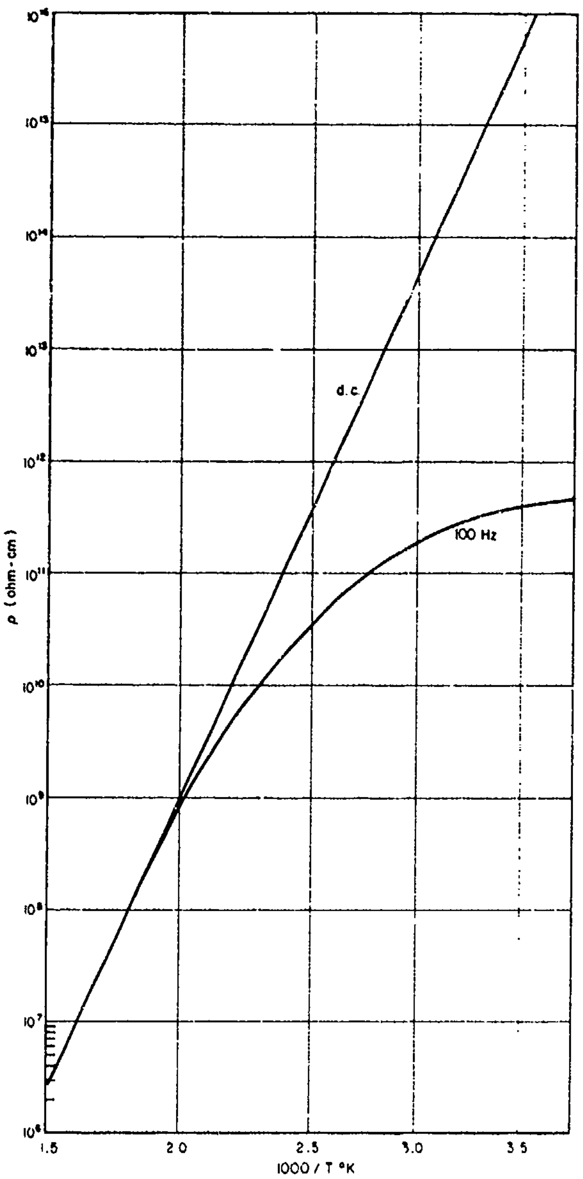
L1957

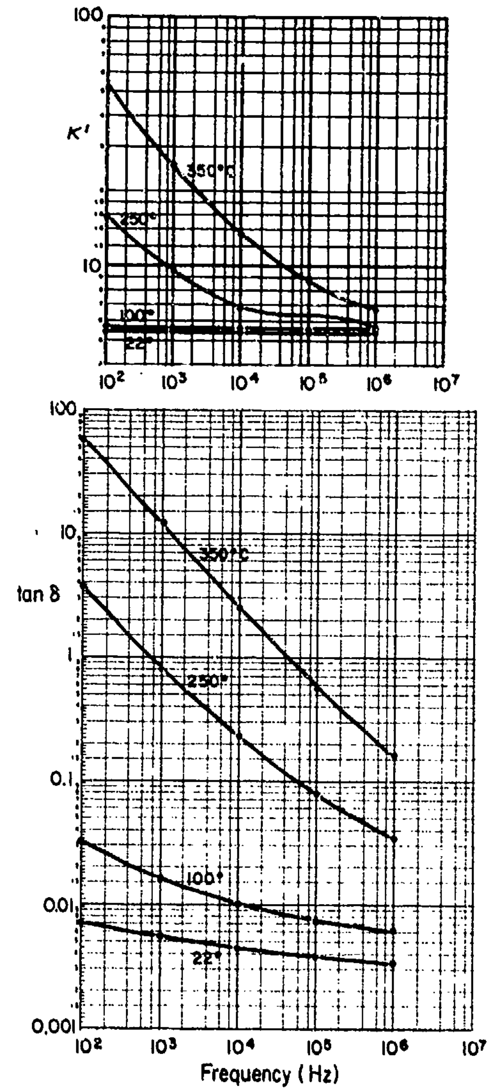




Lancaster glasses (cont.)

No. L 8100





Mixed silicate glasses (cont.)

M.I.T., Laboratory for Insulation Research

Soda silicate glass	50 GHz κ	tan $\delta \times 10^{-4}$
1) 9% Na_2O, 91% SiO_2	4.90	158
2) 12% Na_2O, 88% SiO_2	5.08	178

Sample EE 9

Sample EE 10

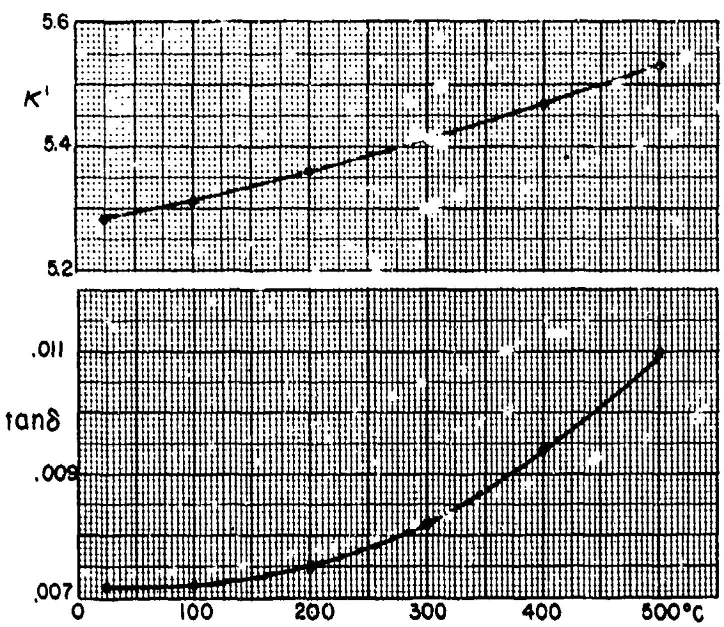
Owens-Illinois
Toledo, Ohio 43601

EE 9 Freq., 8.52 GHz			EE 10 Freq., 8.52 GHz		
$T^{o}C$	κ	tan δ	$T^{o}C$	κ	tan δ
25	5.84	.0070	25	8.17	.0082
97	5.86	.0070	97	8.25	.0082
199	5.90	.0071	202	8.36	.0083
314	5.97	.0072	292	8.47	.0084
421	6.02	.0073	416	8.63	.0089
506	6.03	.0077	501	8.76	.0096
607	6.17	.0081	605	8.98	.0123
32	5.82	.0069	27	8.19	.0080

Silicate glasses (cont.)

X994

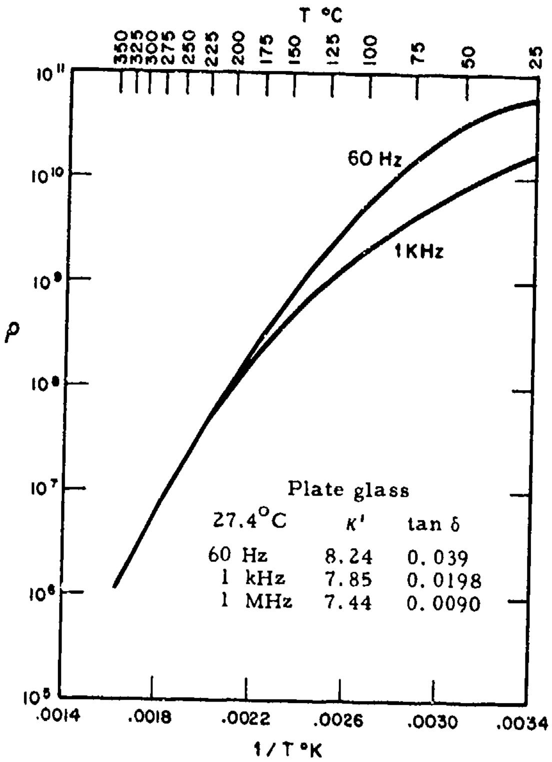
Owens Corning



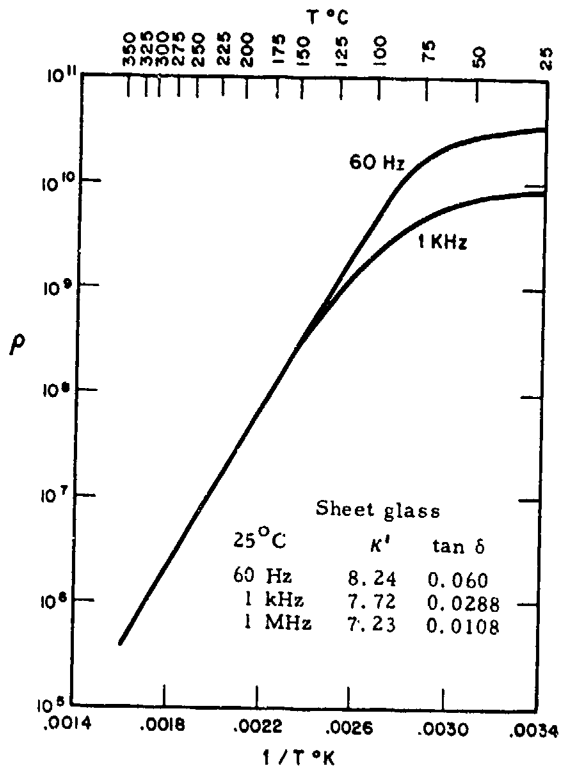
Glasses (cont.)

Pittsburgh Plate Glass Co.

Plate glass



Sheet glass



Silicon dioxide, sintered

Slip-cast | Brunswick

Density 1.957 g/cm^3

	25°C		100°C		200°C		300°C		400°C		500°C	
Freq.,Hz	κ	10^4tanδ	κ	10^4tanδ	κ	tan δ	κ	tan δ	κ	tan δ	κ	tan δ
10^2	3.38	7.1	3.39	11.0	3.44	.0190	4.42	.896	7.91	9.51	19.1	33.8
$3x10^2$	3.38	8.6										
10^3	3.38	8.8	3.38	7.8	3.41	.99364	3.64	.178	5.09	1.66	7.57	9.00
$2x10^3$	3.38	7.3										
$5x10^3$			3.38	7.7								
10^4	3.37	6.2	3.38	7.6	3.41	.00158	3.47	.0246	3.90	.334	5.10	1.47
$5x10^4$			3.38	8.3					3.5			
10^5	3.37	4.5	3.37	8.3	3.41	.00099	3.46	.00465	3.54	.055	3.90	.290
$2x10^5$			3.37	7.5								
10^6	3.37	3.7	3.37	6.1	3.40	.00081	3.45	.00158	3.49	.0089	3.61	.0483
$6x10^6$			3.37	3.6								
10^7	3.37	2.5	3.37	3.2	3.40	.00068	3.45	.0008	3.49	.0021	3.55	.o112
$8.5x10^9$	3.364	6.6										

Silicon dioxide, with 2.5% chromium oxide | Brunswick

Slip-cast,

Density 1.928 g/cm^3

	25°C		100°C		200°C		300°C		400°C		500°C	
Freq.,Hz	κ	tan δ	κ	tan δ	κ	tan δ	κ	tan δ	κ	tan δ	κ	tan δ
10^2	3.33	.00345	3.43	.0057	3.57	.0292	4.59	.935	8.73	9.39	36.7	42.4
10^3	3.33	.00257	3.42	.0043	3.51	.0113	3.72	.179	5.17	1.76	13.5	10.1
10^4	3.32	.00174	3.36	.0034	3.48	.0071	3.59	.0292	3.95	.324	6.09	2.41
10^5	3.32	.00152	3.34	.0027	3.40	.0054	3.51	.0109	3.63	.0537	4.39	.425
10^6	3.31	.00093	3.33	.0020	3.38	.0040	3.49	.0101	3.56	.0149	3.82	.094
10^7	3.31	.00035	3.32	.0017	3.34	.0022	3.42	.0076	3.53	.0106	3.68	.032
$8.5x10^9$	3.29	.00112										

Silicon dioxide, sintered

Code 7941 — Corning Glass

Density 1.923 g/cm^3

Freq., ~8.5 GHz

T°C	κ	tan δ
25	3.323	.0005
279	3.351	.0009
517	3.378	.0014
769	3.408	.0023
910	3.431	.0028
1043	3.451	.0037
1205	3.455	.0051
1372	3.513	.0091

Corning Multiform Glass

At 8.52 GHz, 25°C, density = 1.906 g/cm^3

κ = 3.27; tan δ = .00063

Silica, slip-cast — Dynasil Corp. of America

8.6 GHz, 25°C

Sample	Density (g/cm^3)	κ	tan δ
DSCX-3	1.970	3.395	.00058
DSCX-8E	2.038	3.513	.00054

Quartz fiber

Sample AS-3DX-1R

Source: Philco Ford Corp.
Newport Beach, Calif. 92663

Manufacturer: Fiber Materials Inc.
Graniteville, Mass. 01829

Freq., 8.52 GHz

T^oC	κ	tan δ
25*	3.02	.0054
25	2.98	.0019
98	2.97	.0018
198	2.96	.0016
307	2.95	.0015
418	2.95	.0014
497	2.945	.0014
591	2.95	.0016
729	2.96	.0022
828	2.975	.0029
905	2.99	.0035
995	3.01	.0042

* As received, other values after vacuum bake for 24 hours at 125°C.

Silica fiber composites

Philco-Ford Corp., Aeronutronic Div.

<u>Sample</u> 1-VH-O-M-1, 25°C		(Hz) 10^5	10^6	10^7	7.5×10^7	1.8×10^8
As received,	κ	2.779	2.777	2.777	2.775	2.772*
density 1.536 g/cm^3	10^4 tan δ	4.6	8.3	6.4	13.4	17*
After 18 hrs.	κ			2.77	2.77	2.77*
vacuum oven 80°C	10^4 tan δ			4.6	9.1	11.5*

* Extrapolated values.

Silica fiber composites (cont.) — Philco-Ford Corp., Aeronutronic Div.

Sample 1-XB-0-M

Density 1.653 g/cm^3

		8.52 GHz	
	T°C	κ	tan δ
As received, Face 1 up	25	2.919	.0062
Face 2 up	25	2.956	.0064
After vacuum oven 80°C, 10 days			
Face 2 up	25	2.938	.00162
Face 1 up	25	2.895	.00169
	115	2.89	.0012
	246	2.89	.0006
	357	2.90	.0005
	438		.0006
	535		.0008
	608		.0010
	710		.0014
	805		.0020
	908		.0026
	972		.0028
	1000	*	.0031*
* Extrapolated values.	25	2.89	.00042

Sample AS-3DX 176-17 at 8.5 GHz, density = 1.626 g/cm^3

T°C	κ	tan δ
25	2.873 ± .005	.00355
94	2.86 ± .01	.00199
203	2.86	.00054
288	2.85	.00040
377	2.85	.00043
466	2.85	.00054
535	2.86 ± .02	.00068
289	2.85	.00042
27	2.840 ± .005	.00038 ± .00003

Silica fibers in aluminum phosphate matrix Whittaker Corp.

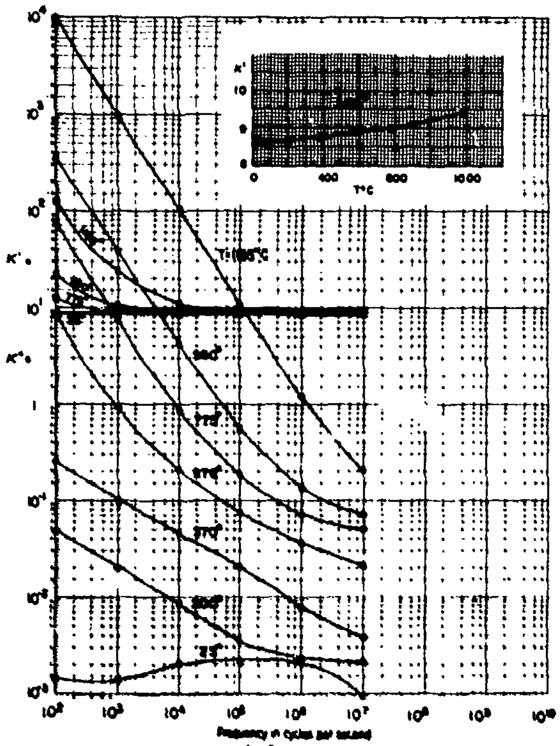
ChemCeram

		8.52 GHz		
Sample	T°C	κ	tan δ	Density (c/cm^3)
1, as received	5	2.73	.0051	1.547
2, as "	25	2.70	.0060	1.543
2, dried*	25	2.68	.0043	(wt. loss .049%)
2, room humidity	25	2.70	.0050	
	116	2.70	.0050	
	235	2.71	.0053	
	410	2.71	.0080	
	495	2.71	.0105	
	580	2.72	.0140	
	673	2.72	.0177	
	760	2.72	.0228	
	827	2.73	.0265	
	916	2.74	.0315	
	967	2.75	.038	
	25	2.71	.0047	

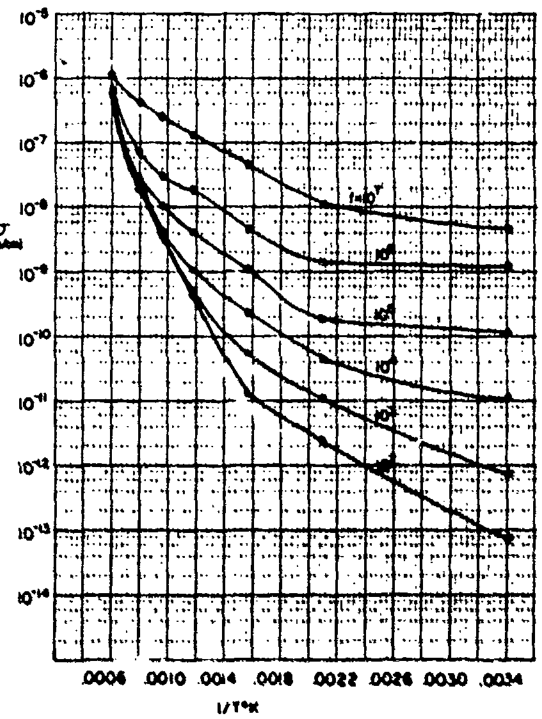
* 4 days at 120°C in vacuum oven.

Silicon nitride, pyrolytic

North American Aviation



(a)



(b)

Silicon nitride ceramic

Admiralty Materials Laboratory

At 8.52 GHz, density 2.449 g/cm^3

T^oC	κ	tan δ
25	5.54	.0036
170	5.54	.00375
323	5.54	.0040
446	5.55	.00365
586	5.55	.0030
674	5.56	.0050
714	5.57	.0054
864	5.58	.00615
912	5.59	.00630
991	5.63	.00665
509	5.55	.0034
348	5.54	.0040

Silicon nitride ceramic,
after vacuum drying at 100°C, at 8.5 GHz
Density 2.128 g/cm^3

Raytheon Company

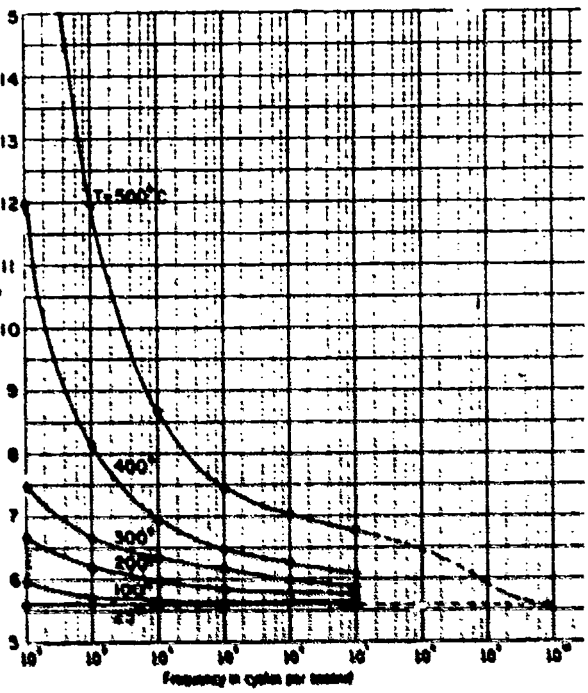
T^oC	κ	tan δ
25	5.15	0.00037

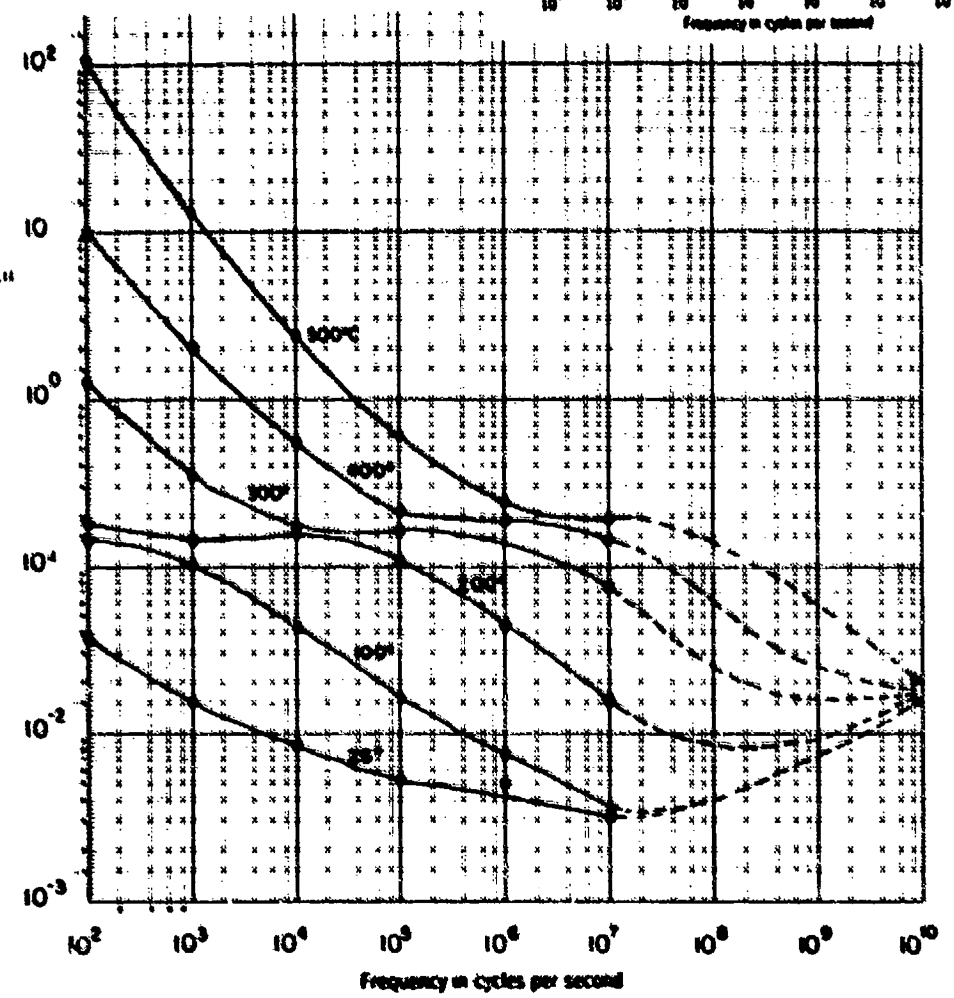
Silicon nitride ceramic,
technical grade,
density 2.456 g/cm^3,
measured in dry nitrogen

Haynes Stellite
Division of Union Carbide

(a)

Dielectric constant
vs. frequency



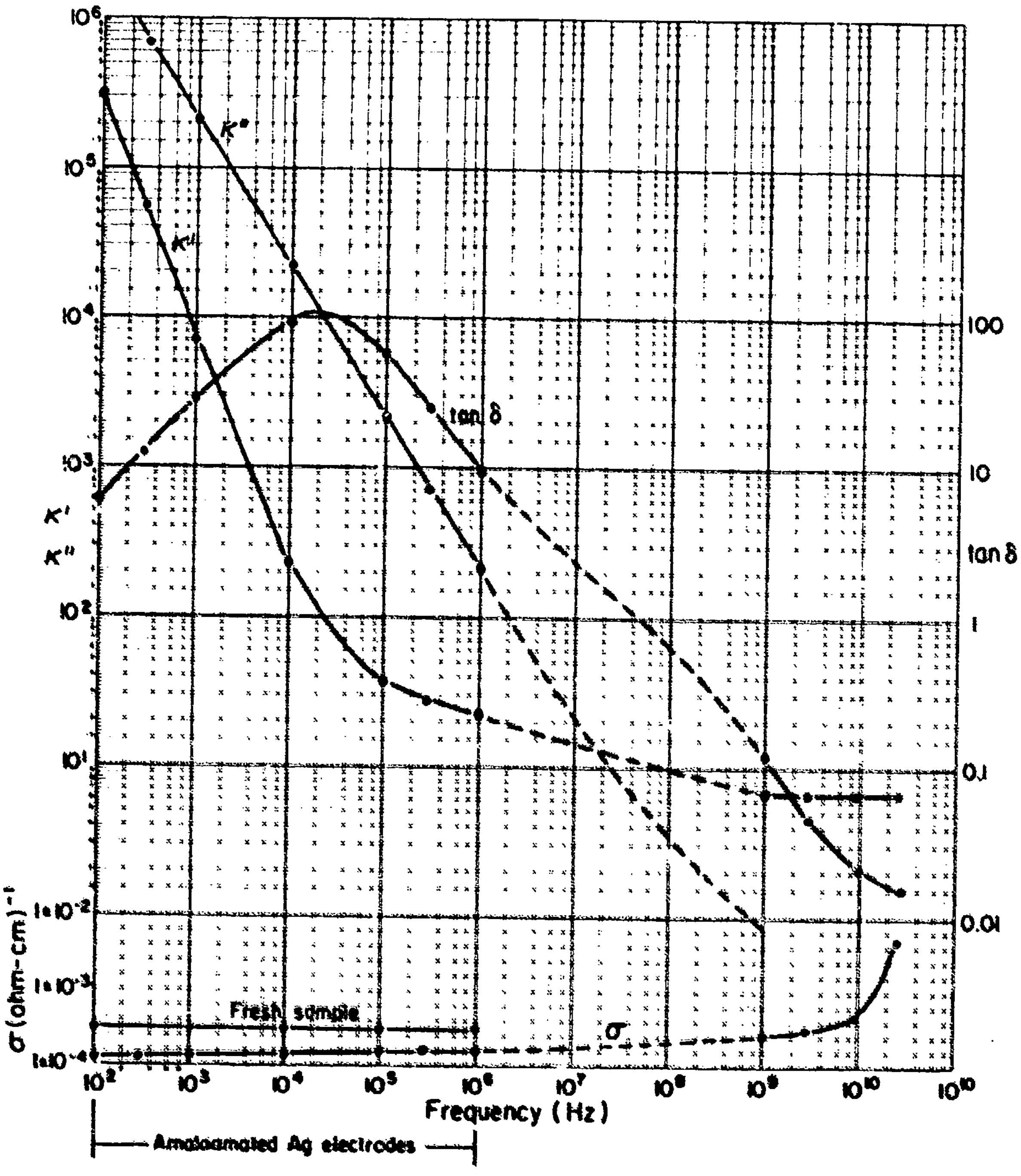


(b)

Dielectric loss
factor versus
frequency

Silver iodide, pressed powder
at 10,000 psi, 27°C,
aged several weeks
unless noted

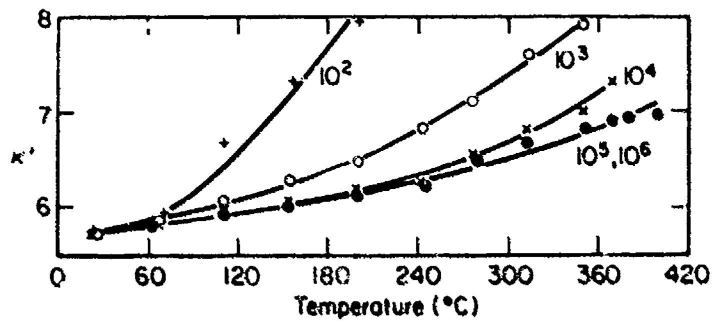
Massachusetts Institute of Technology
Laboratory for Insulation Research



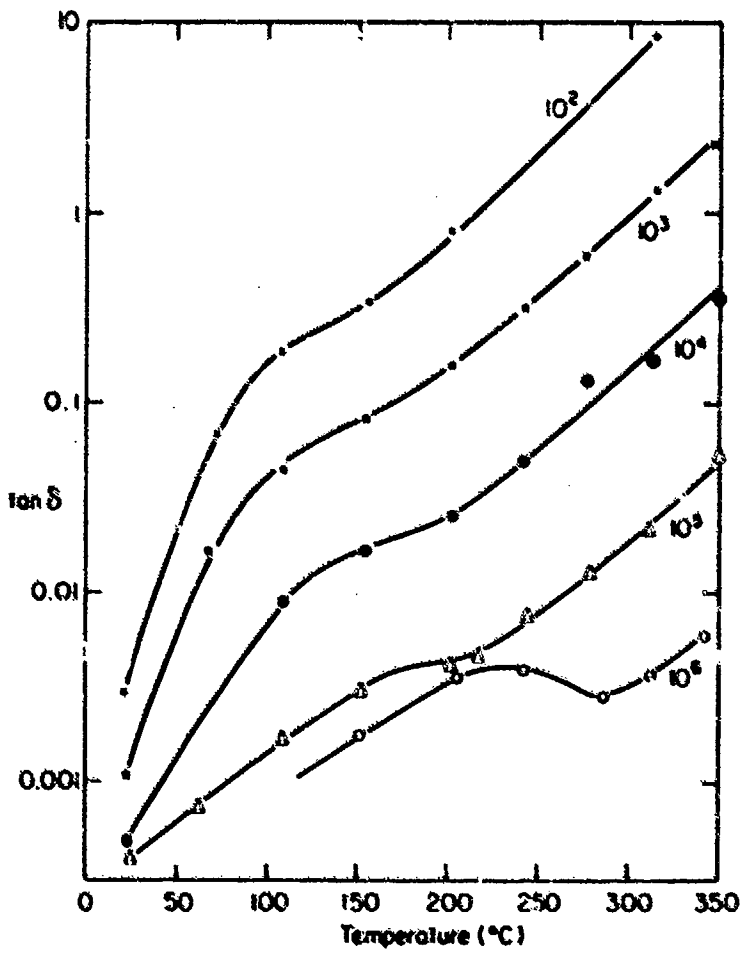
Sodium chloride, doped (0.075 mole % $BiCl_3$)

M.I.T., Crystal Physics Laboratory

Variation of dielectric constant with temperature at different frequencies

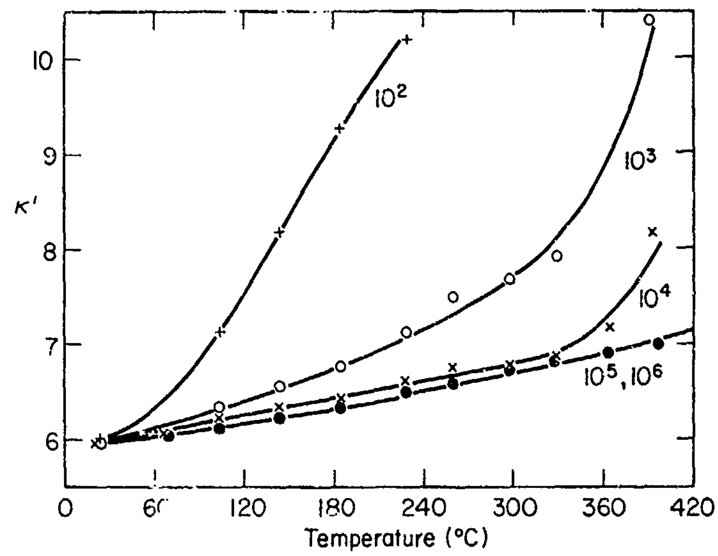


Dielectric loss as a function of temperature at different frequencies

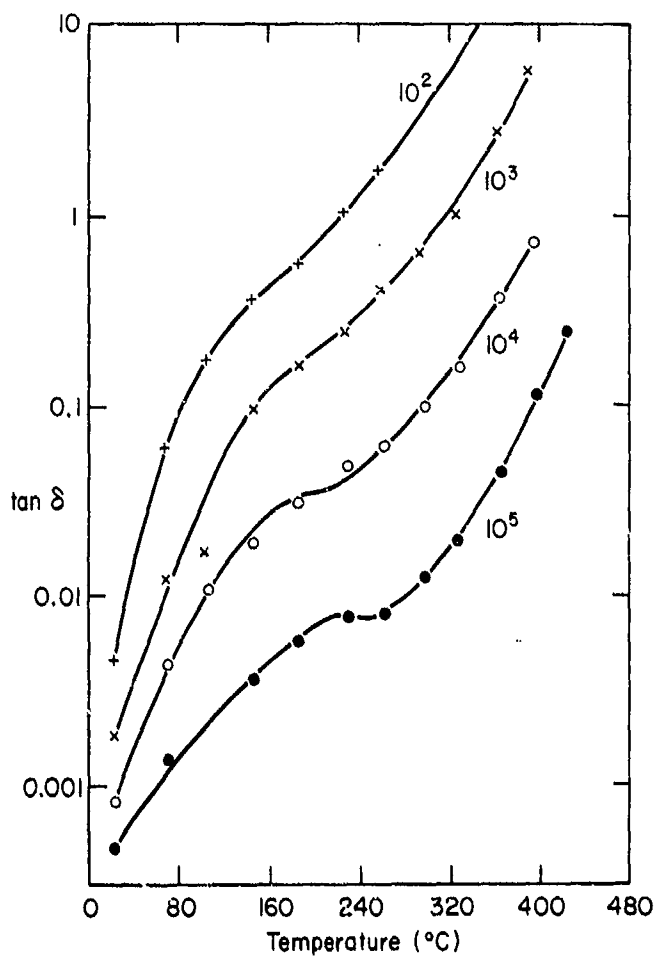


Sodium chloride, doped (cont.)
(1.23 mole % $BiCl_3$)

Variation of dielectric constant with temperature at different frequencies



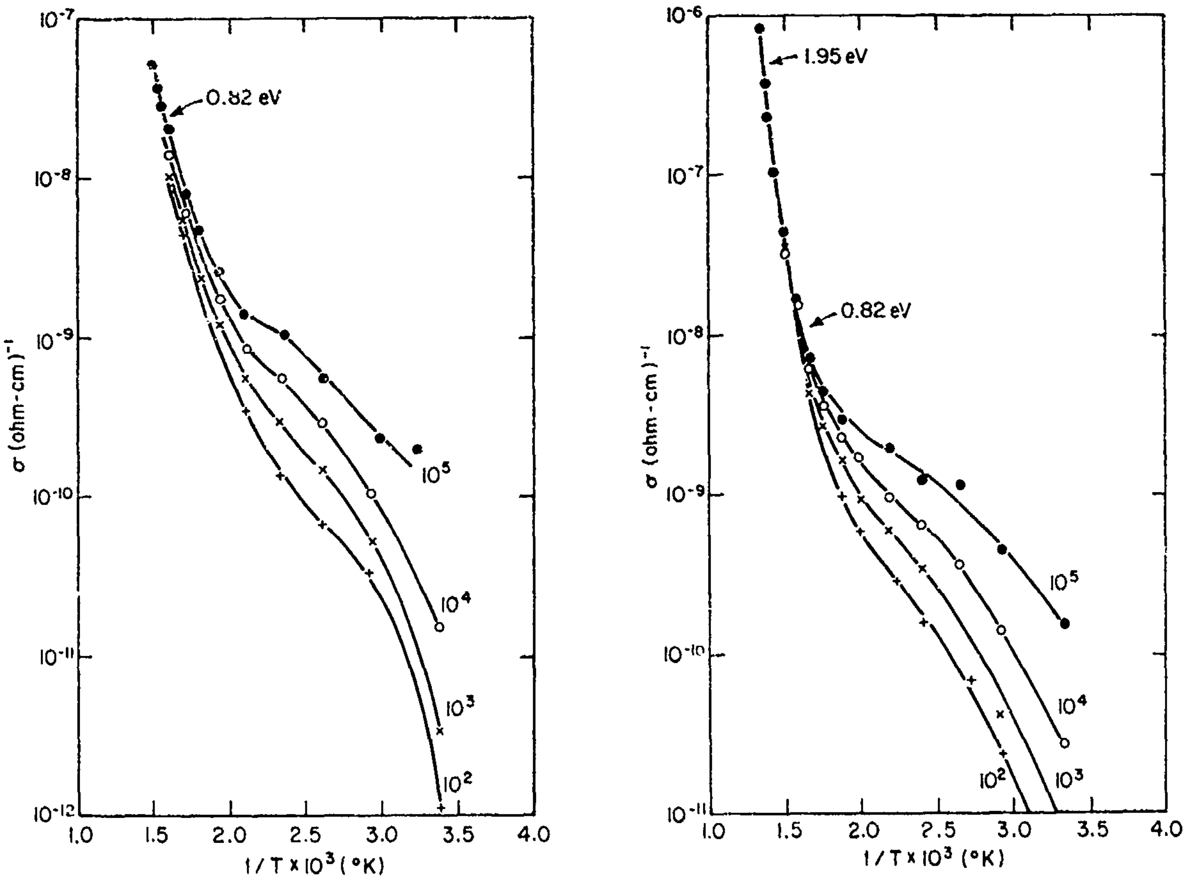
Dielectric loss as a function of temperature at different frequencies



Sodium chloride (cont.)

Specific conductivity as a function of 1/T
at different frequencies

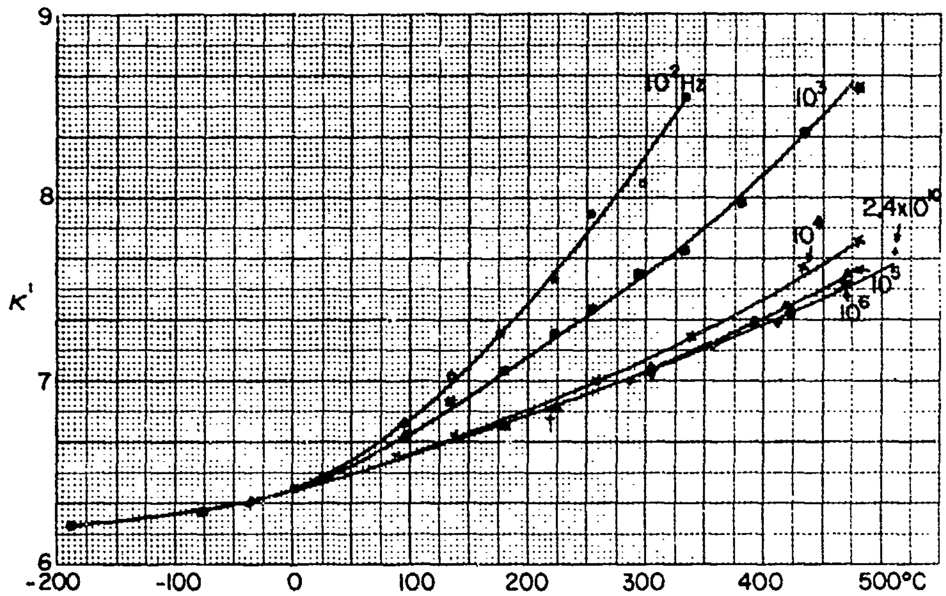
(0.075 mole % $BiCl_3$) (1.23 mole % $BiCl_3$)

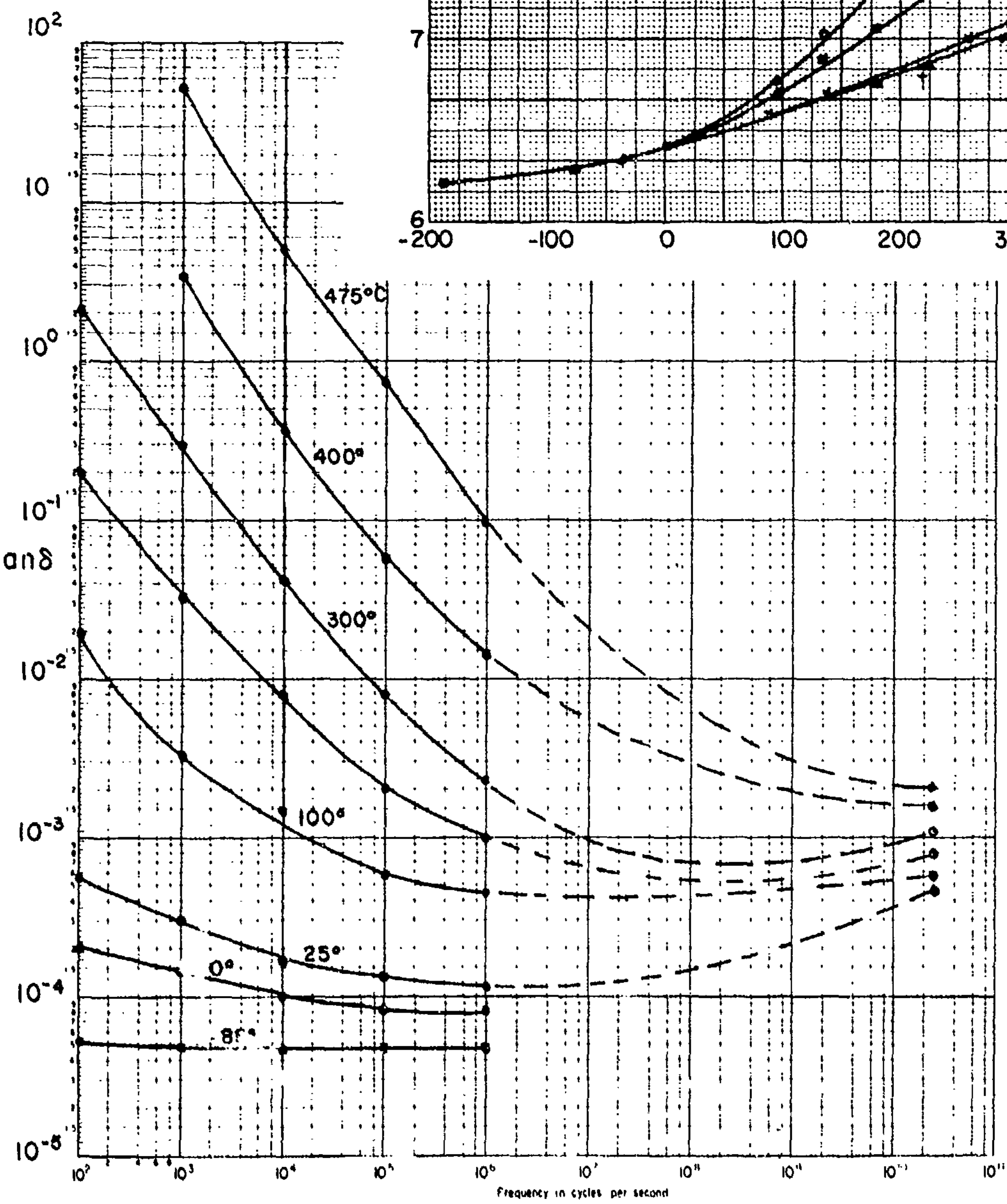


Strontium fluoride

M.I.T., Crystal Physics Lab.

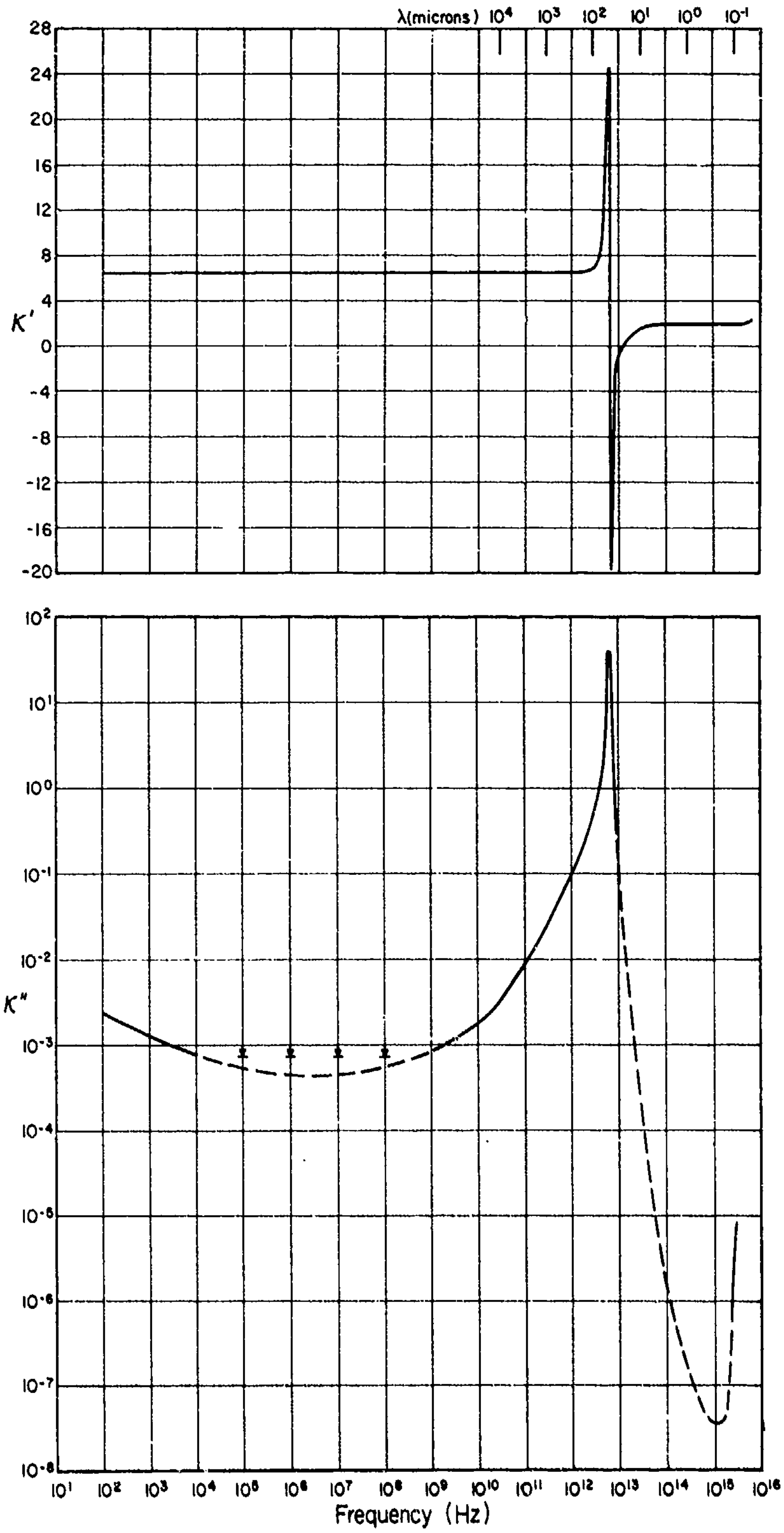
For more complete data see
K. V. Rao and A. Smakula,
J. Appl. Phys. 37, 319 (1966).





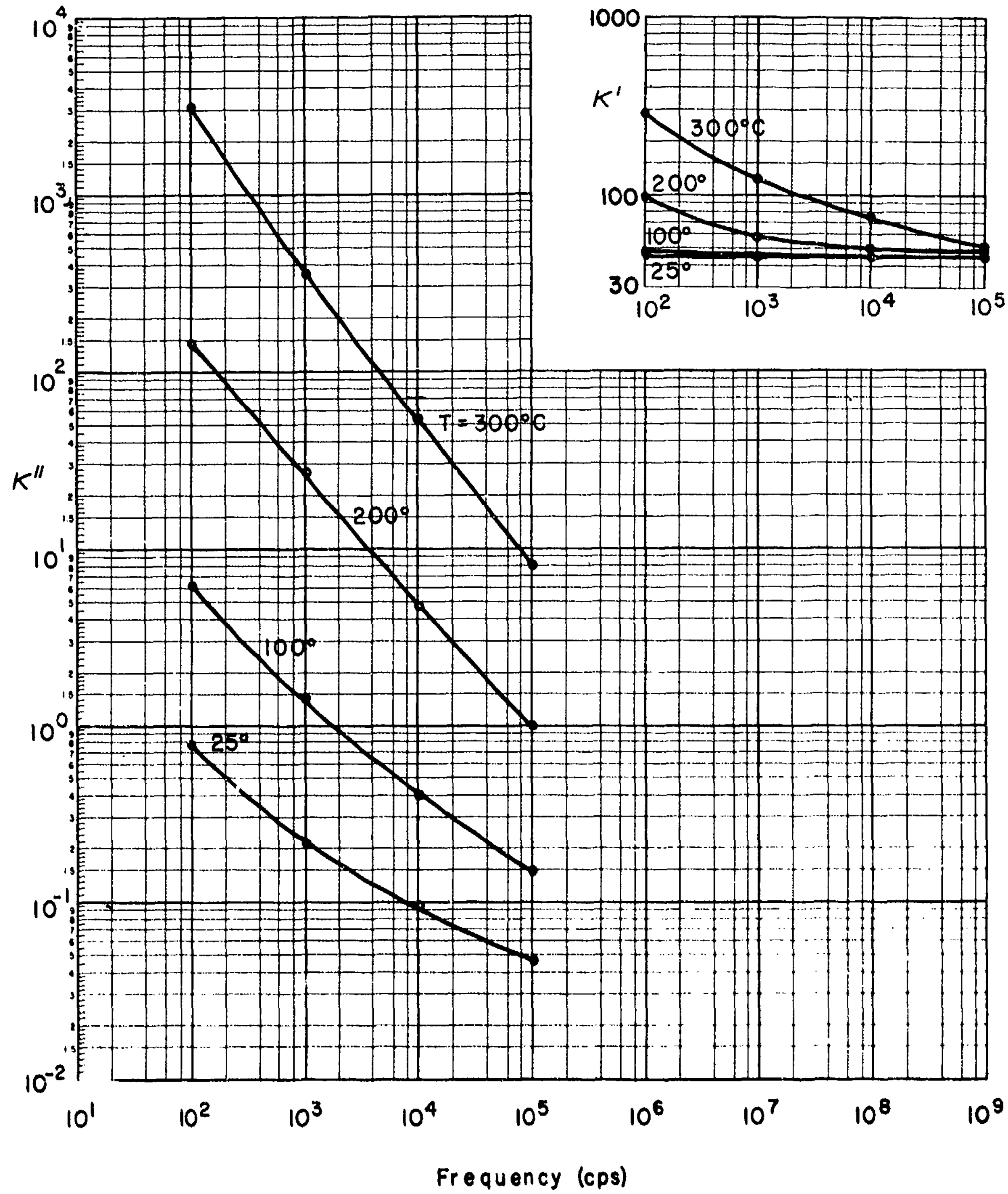
Strontium fluoride (cont.)
Single crystal

M.I.T., Crystal Physics Lab.



Ta_2O_5 ceramic, hot-pressed from Ciba optical grade powder, density 8.27 g/cm^3

Massachusetts Institute of Technology
Laboratory for Insulation Research

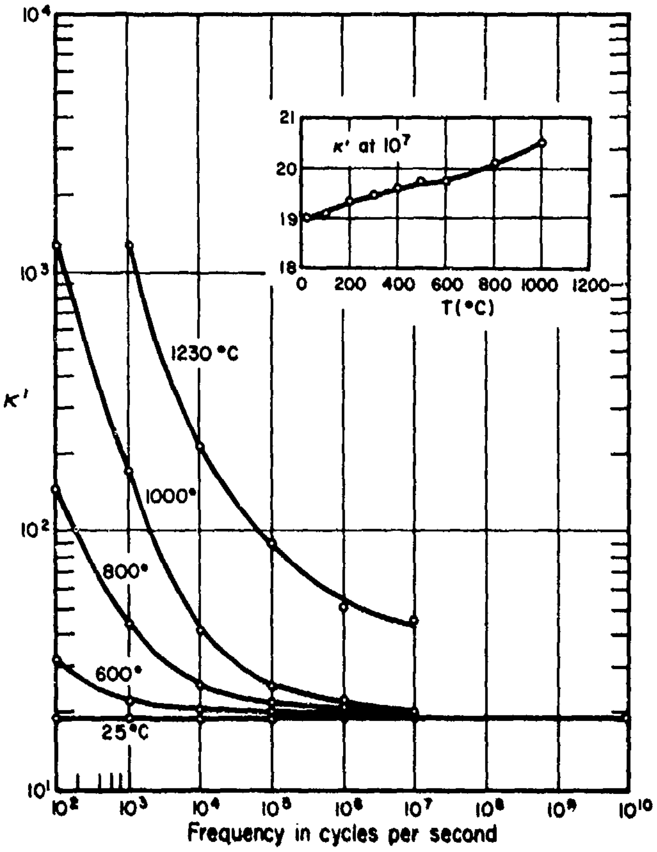


Thallium halides M. I. T., Crystal Physics Lab.

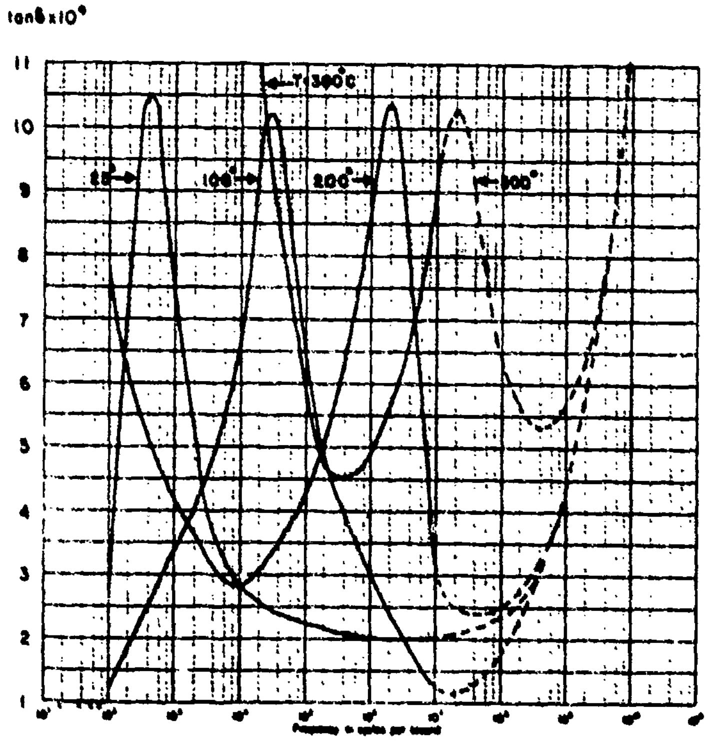
Material	κ', 25°C 10^6 Hz	κ', 4°K	tan δ, 25°C 10^6 Hz	Activation energy for conduction in eV
TlF pressed	19.7	-	.00015	-
TlCl	31.9	-	.00006	.73
TlBr	30.4	-	.00005	.77
TlI polycrystalline	20.4	20.0	.00024	-
KRS6 $(TlCl)_{.7}$-$(TlBr)_{.3}$	32.2	38.4	.000075	.71
KRS5 $(TlBr)_{.42}$-$(TlI)_{.58}$	32.4	-	.00016	.66
TlI + $CsI_{.01}$	32.5	39.4	.000068	.65

For more complete data see reports under Contract AF 19(628)-395.

Thorium oxide ceramic, nuclear grade Zircoa, measured in air except at room temperature in dry nitrogen. Densities: of disk 9.852 g/cm^3; cylinder 9.774 g/cm3



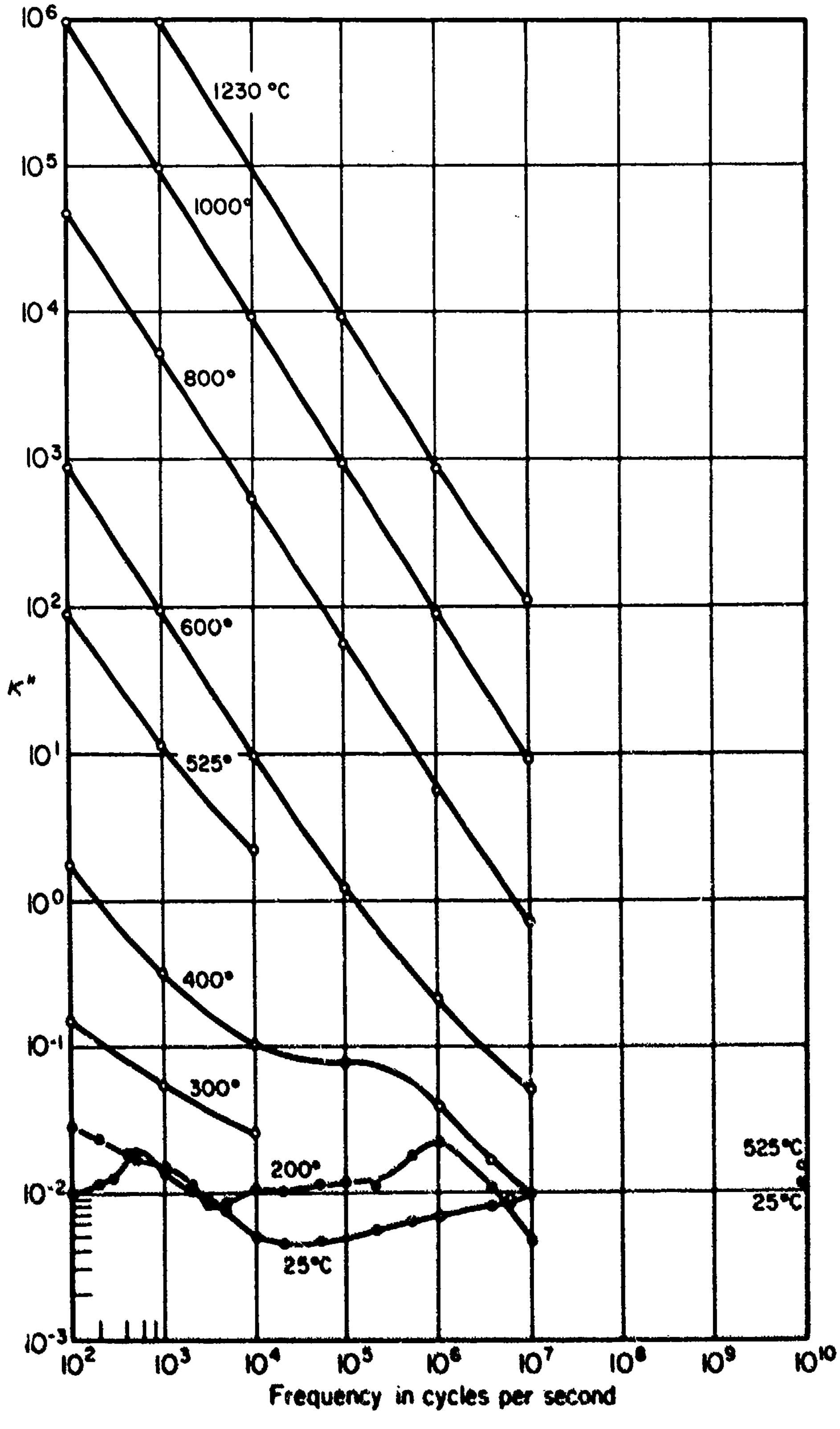
Dielectric constant κ'' vs. frequency and temperature shows build-up of low-frequency polarization and small temperature coefficient at 10^7 Hz.



Dielectric loss tangent at low temperatures shows peak moving to high frequencies with a low activation energy (0.51 eV).

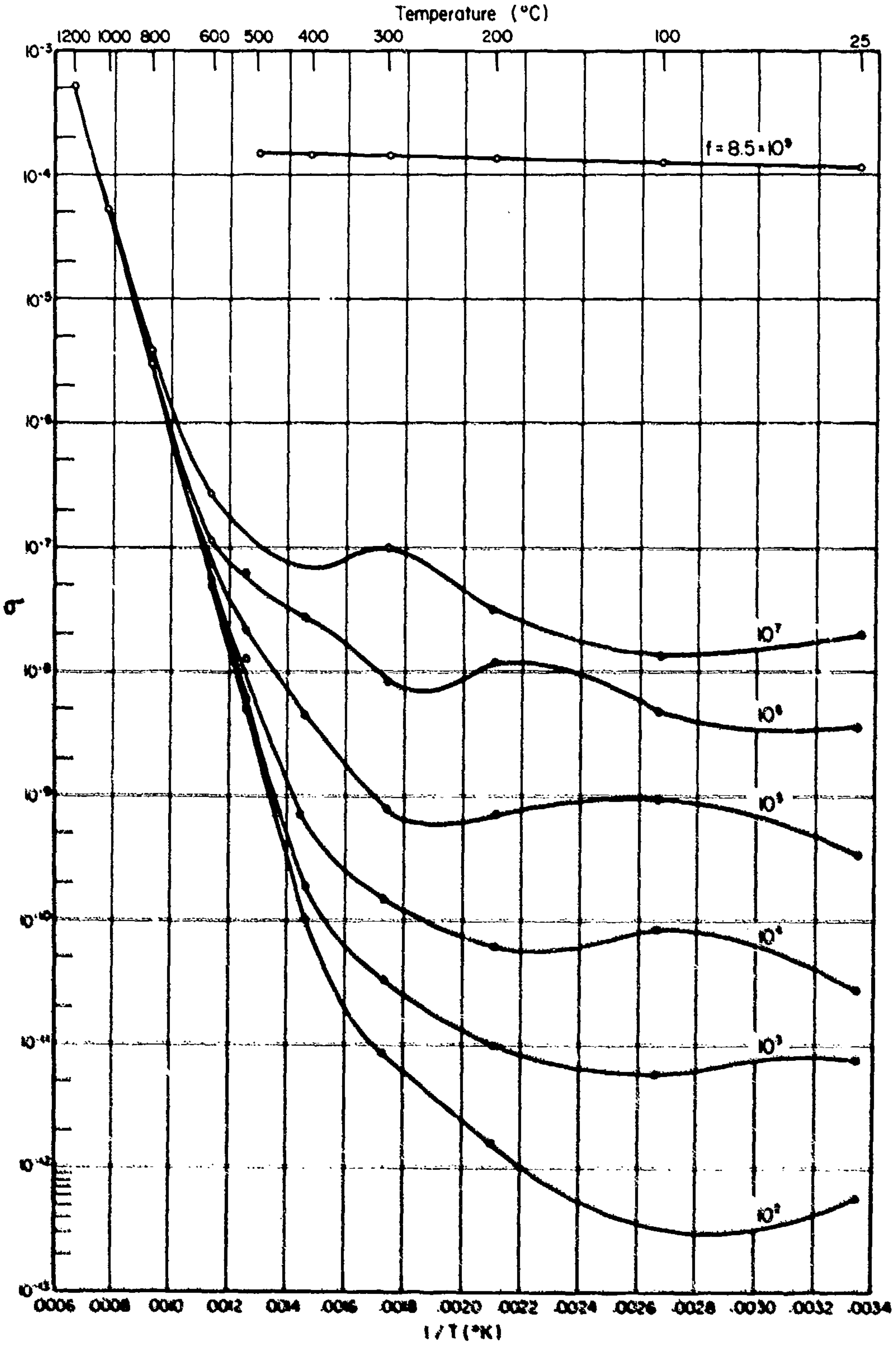
Thorium oxide ceramic (cont.)

Dielectric loss factor κ'' versus frequency shows ease of conduction when many hot electrons are available

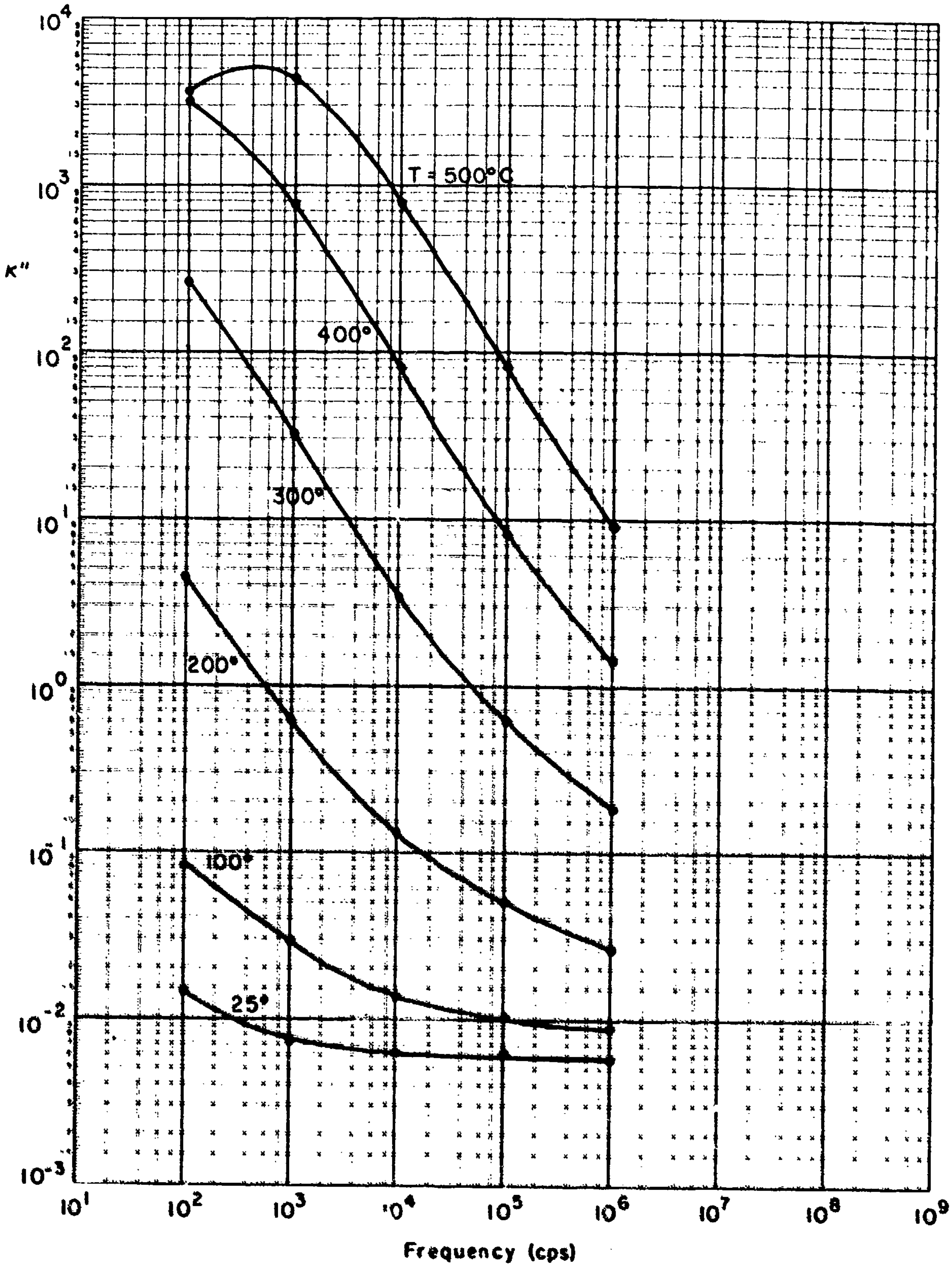


Thorium oxide ceramic (cont.)

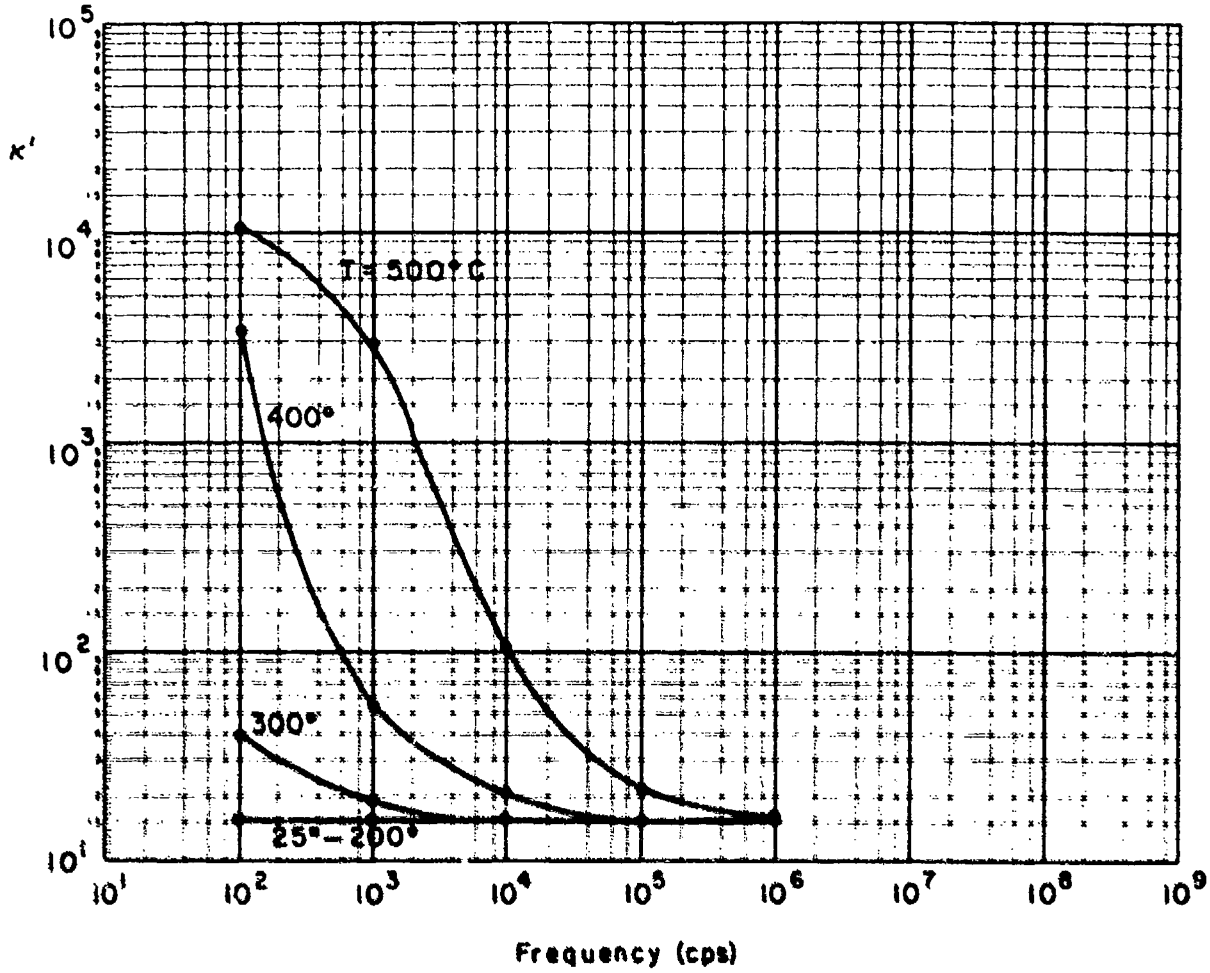
Conductivity vs. reciprocal temperature shows intrinsic conduction range having activation energy of 1.70 eV.



ThO_2 ceramic, Laboratory for Insulation Research; minor constituents Mg, Pb, Zn; traces of Ca, Cu, Fe, Si; density = 8.77 g/cm^3



ThO_2 ceramic, Laboratory for Insulation Research; minor constituents Mg, Pb, Zn; traces of Ca, Cu, Fe, Si; density - 8.77 g/cc.



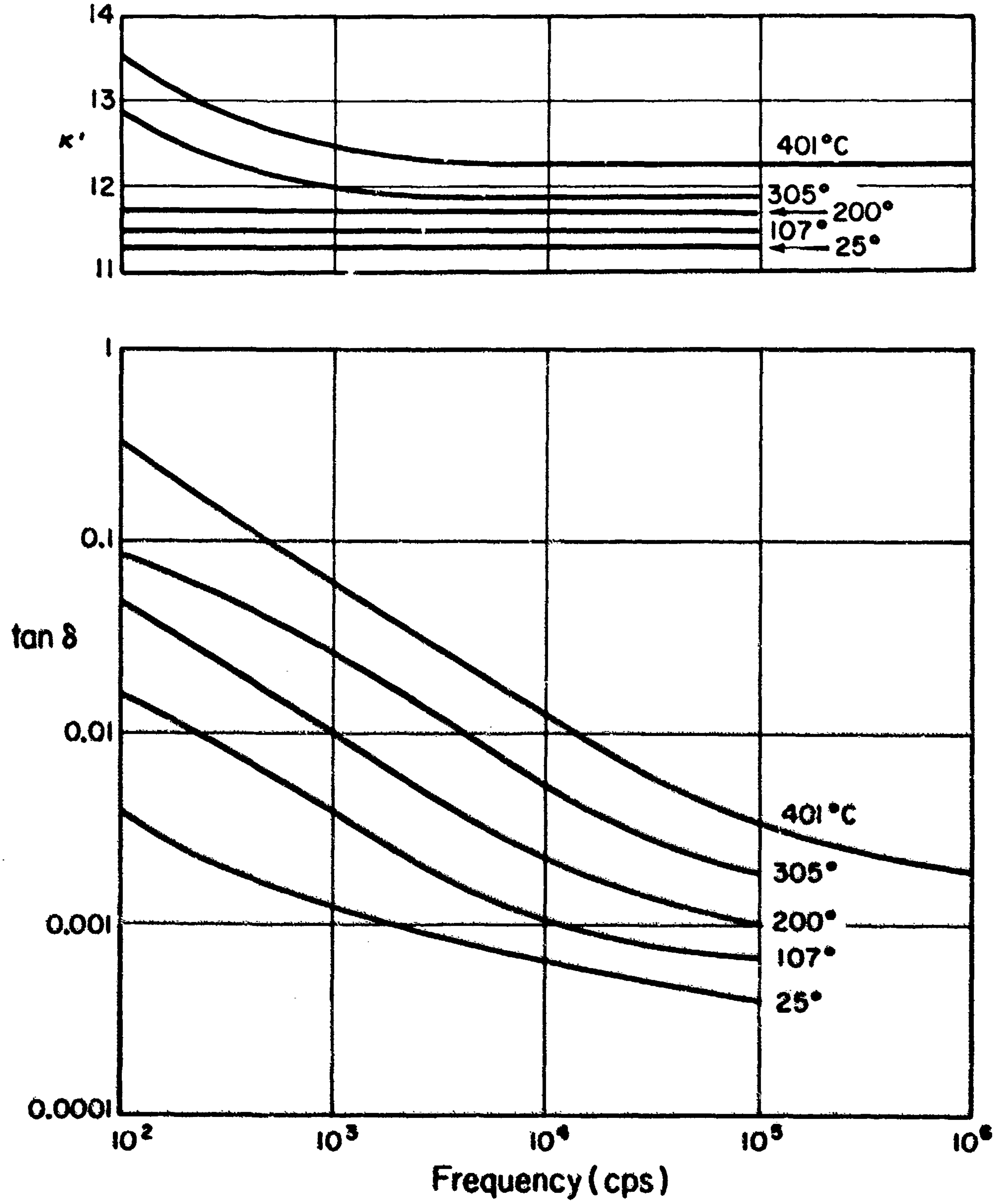
Vanadium oxide (V_2O_3) **M.I.T., Lab. Ins. Research**

Pressed powder samples, -185°C:

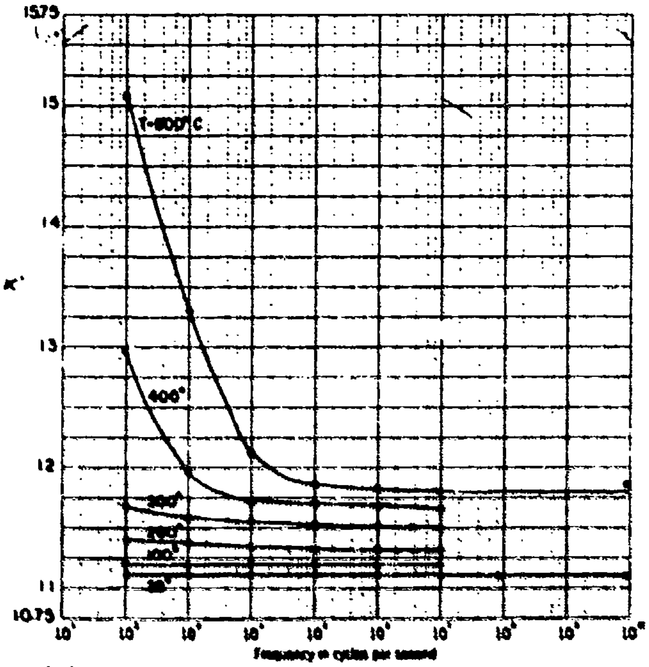
f (Hz)	κ' meas.	κ' corr. to full density	Density g/cm^3
10^5	6.52	15.2	2.60
10^6	4.72	14.5	2.28

Yttrium oxide
Y_2O_3 crystal

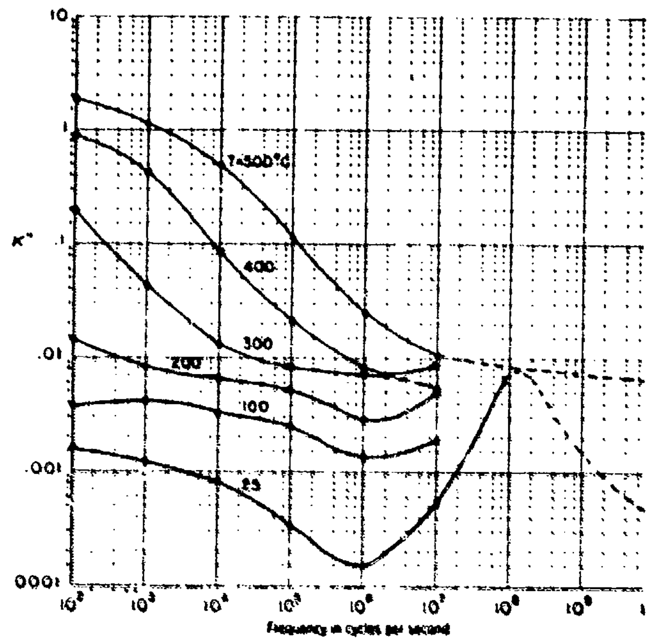
M.I.T., Laboratory for Insulation Res.



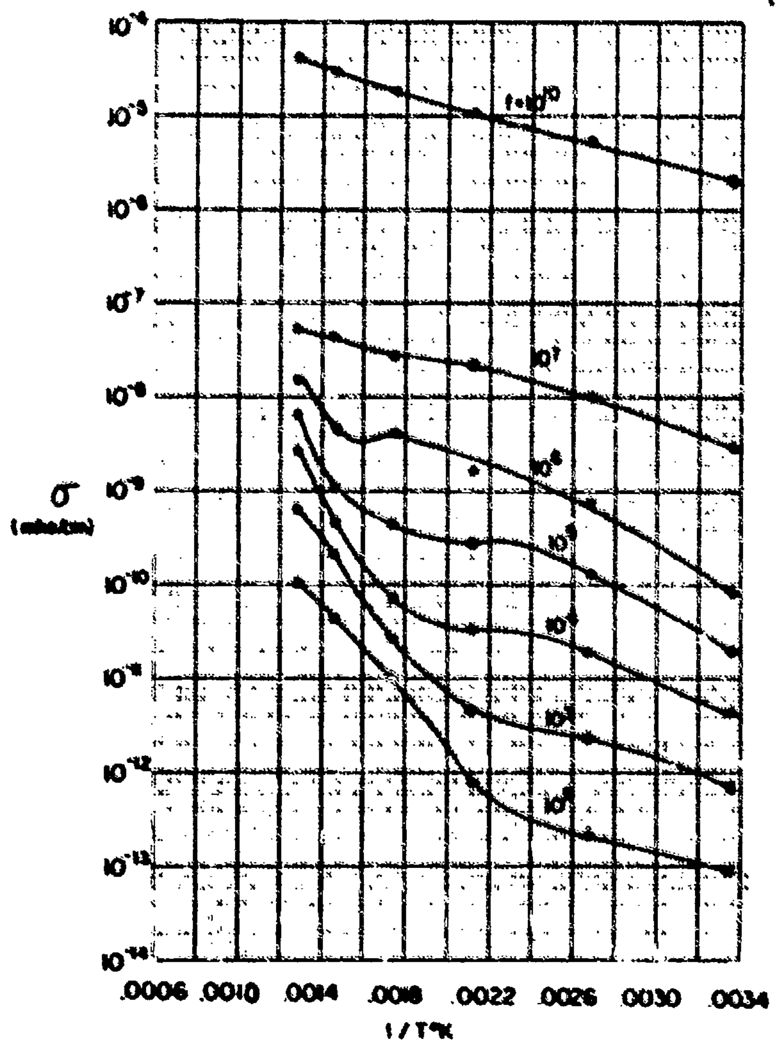
Yttrium oxide, nuclear grade (high purity 99.8%) ceramic, Zircoa; densities: of disk 5.1000, cylinder 4.917 g/cm^3.



(a) Dielectric constant versus frequency



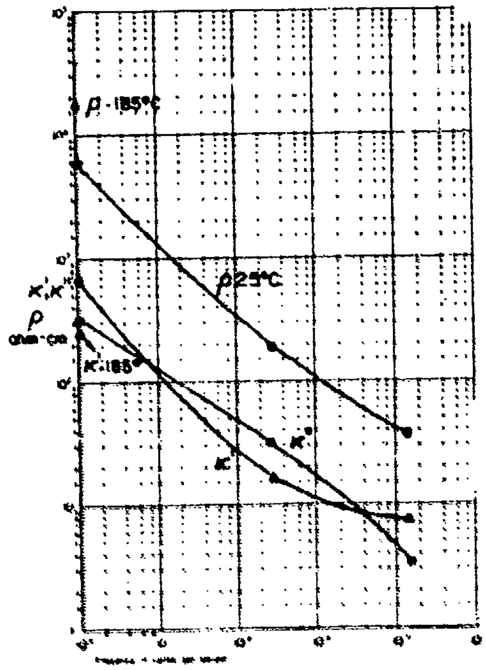
(b) Dielectric loss factor vs. frequency shows two dipole regions



(c) Conductivity versus 1/T does not show intrinsic region

Zinc oxide, single crystal

Airtron Div. of Litton Industries



Measurements of 1 and 300 MHz with electric field ‖ to c axis. At 14 GHz field was perpendicular.

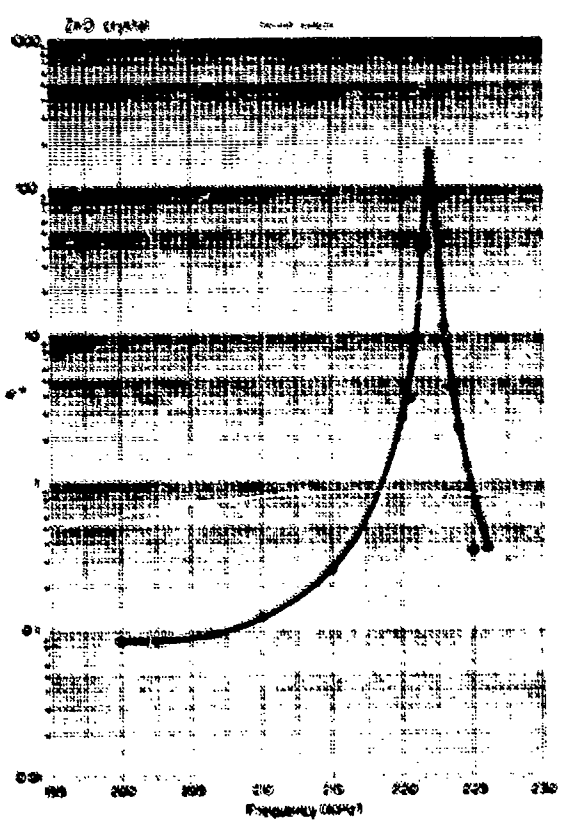
Second sample heat treated

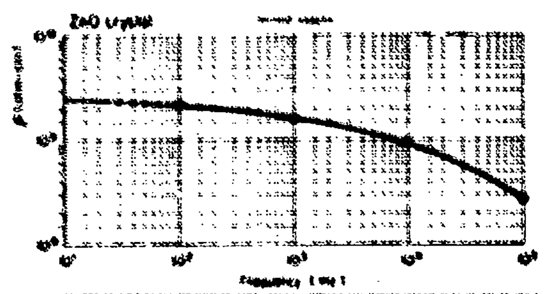
Major frequency resonances (kHz)

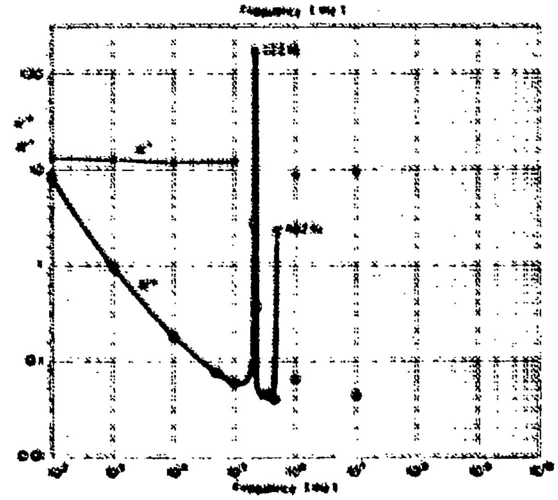
222
482
600
677
740

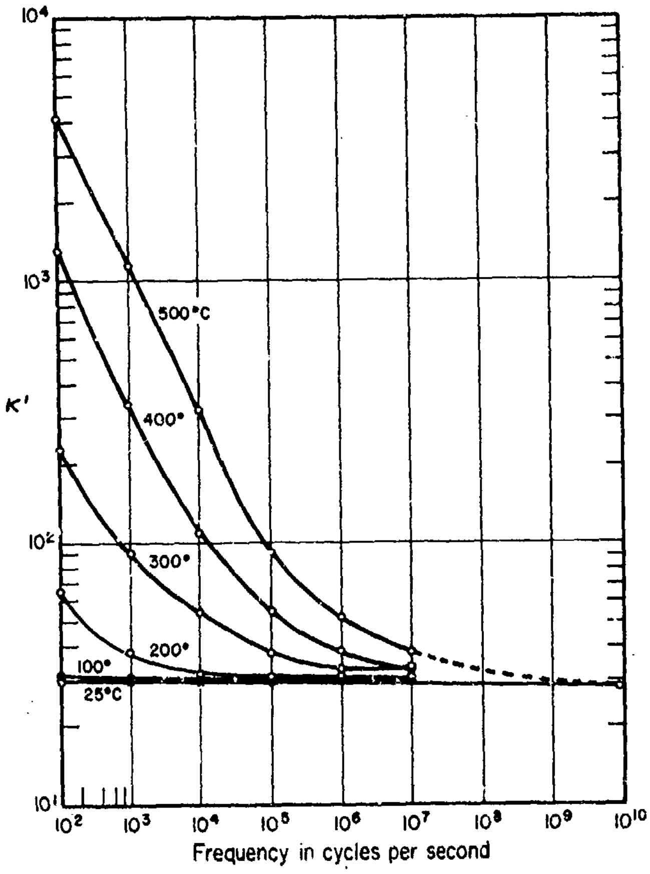
Dielectric constant

Hz	K
10^2	12.29
10^3	12.07
10^4	11.90
10^5	12.13
10^6	8.35
9.5×10^6	



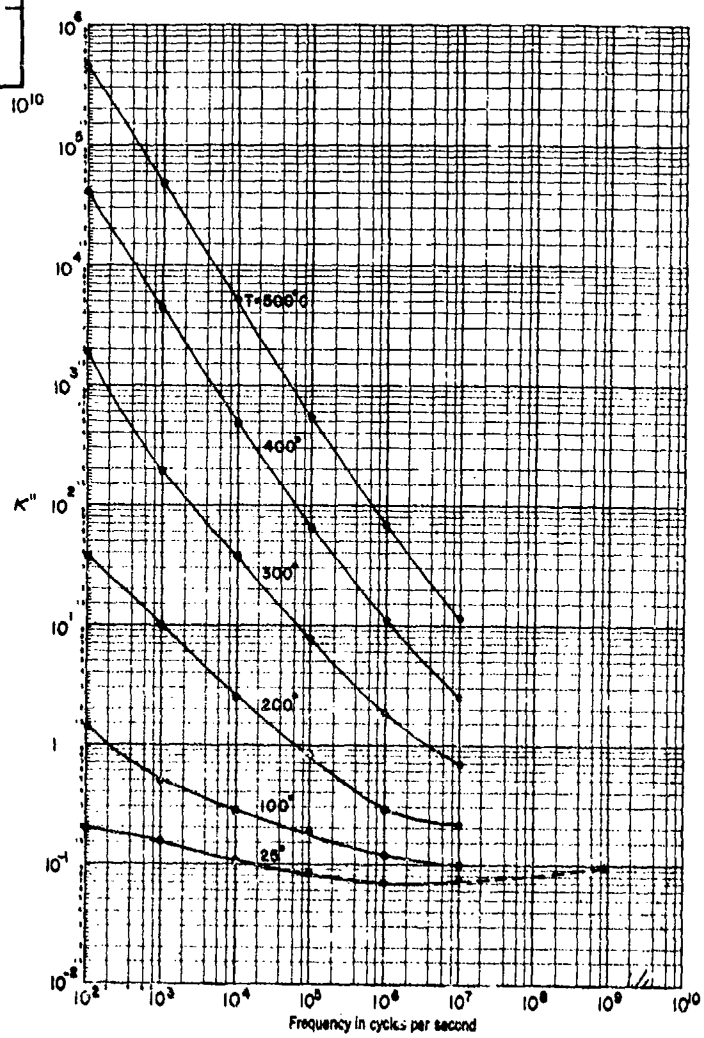




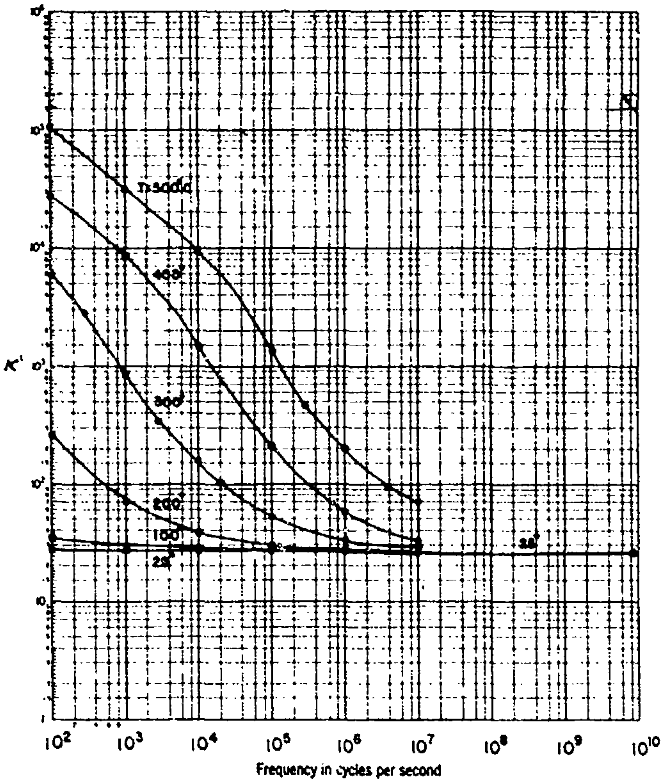


Zirconium oxide (ZrO_2), mono-cubic, stabilized with lime (CaO), technical grade ceramic Zircoa "C", densities of disk 5.696 g/cm3, of cylinder 5.646 g/cm3. Dielectric constant vs. frequency showing large grain-boundary polarization.

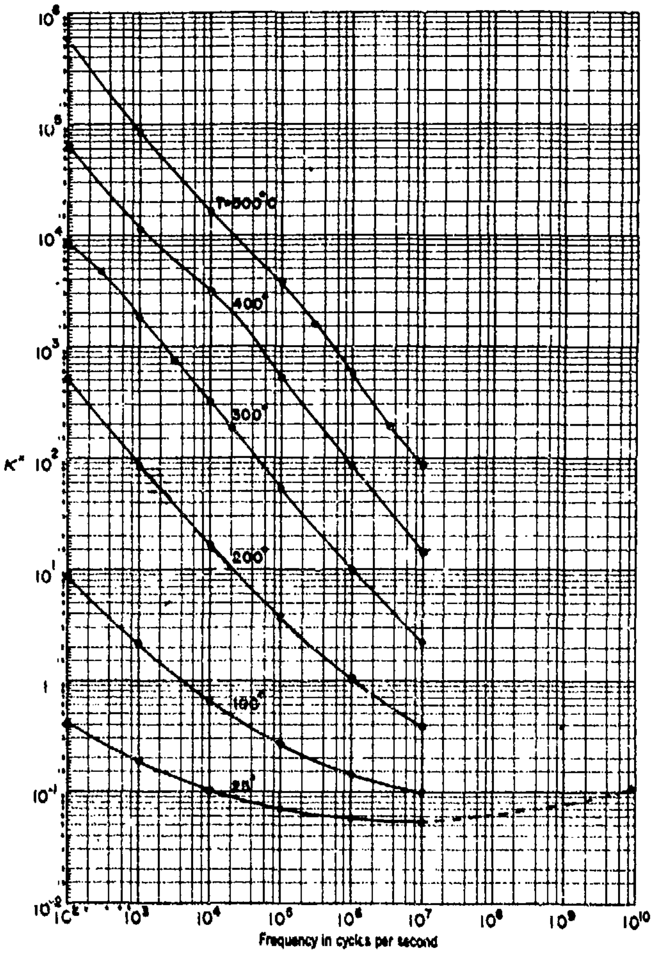
Dielectric loss factor versus frequency.



S‹ ılso page 121

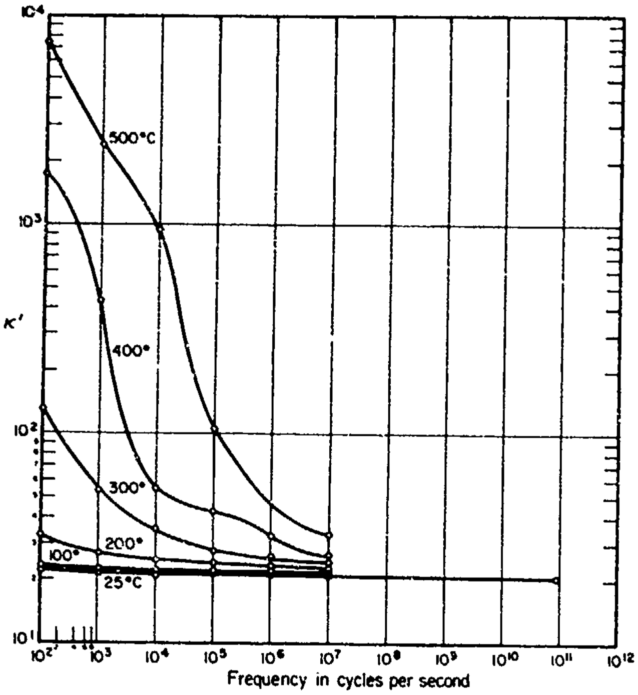


Zirconium oxide stabilized with 8% Y_2O_3 nuclear grade ceramic Zircoa Y-904; densities of disk 5.444 g/cm^3, of cylinder 5.647 g/cm^3. Dielectric constant versus frequency

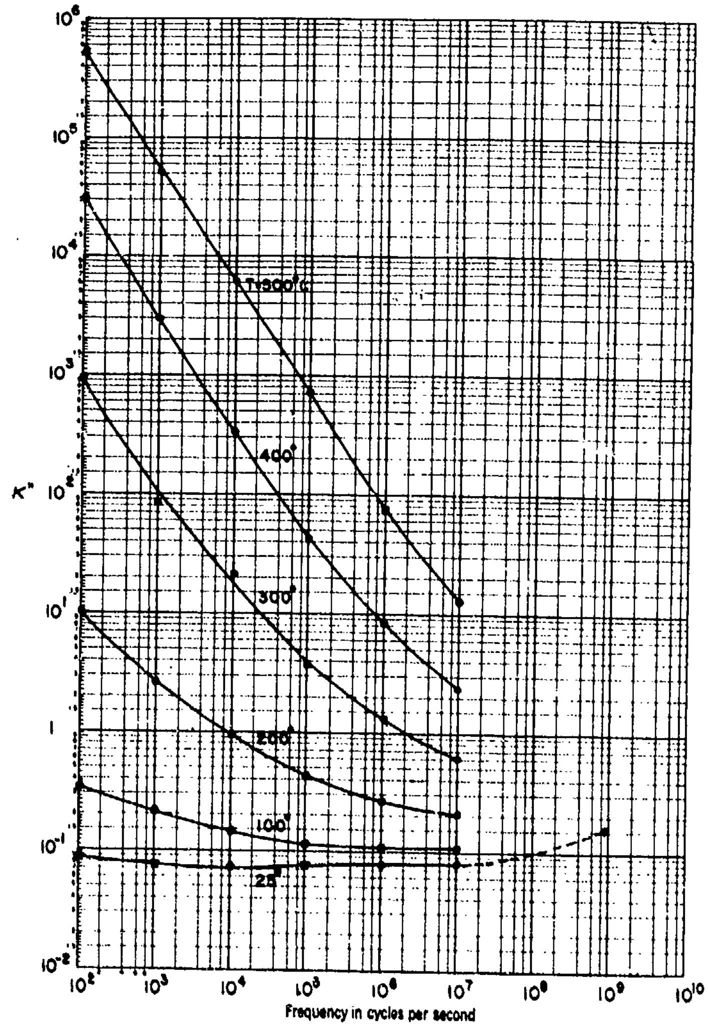


Dielectric loss factor versus frequency

See also p. 121



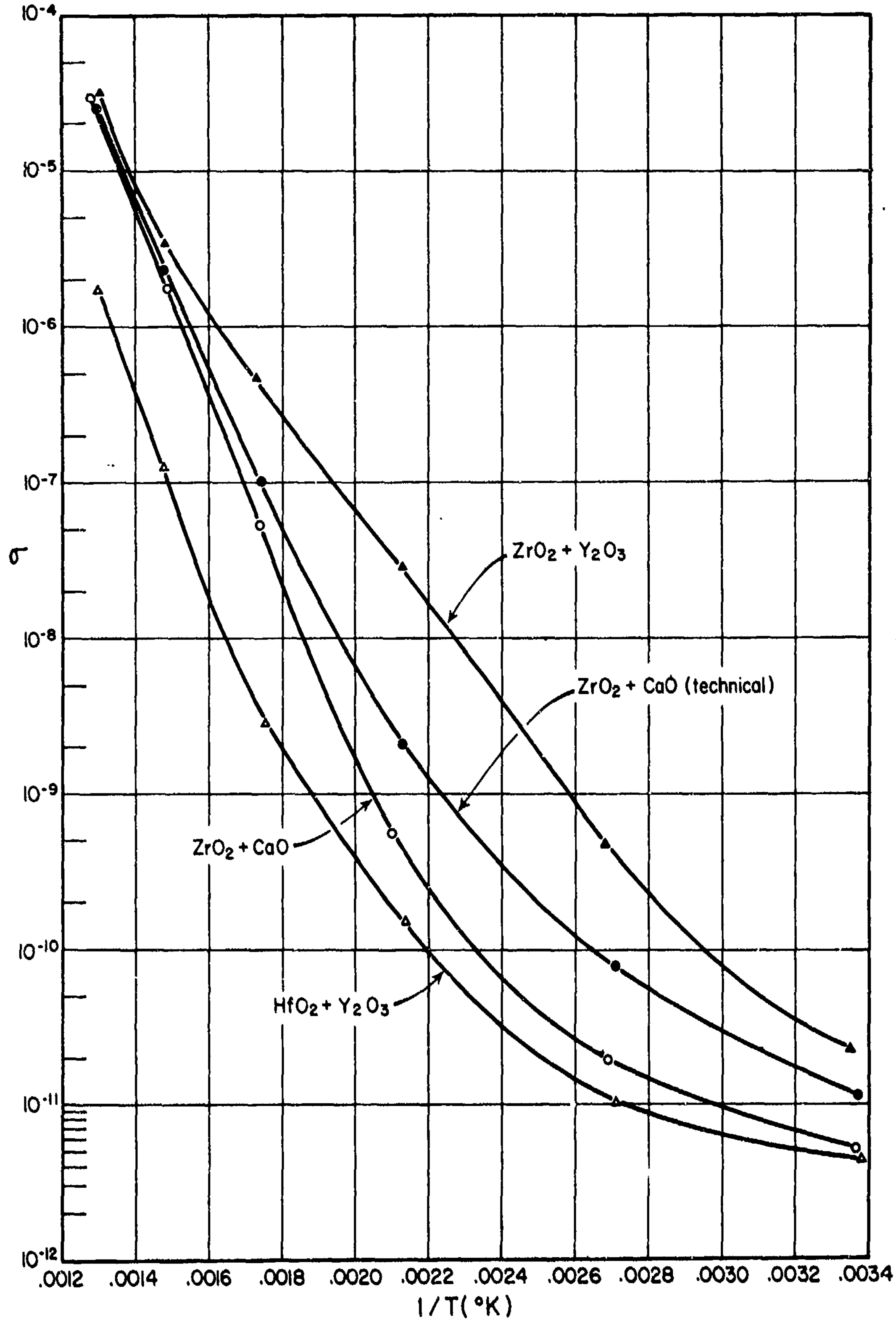
Zirconium oxide stabilized with 7.5% CaO, nuclear grade ceramic Zircoa Y-1362, densities of disk 5.087 g/cm3, of cylinder 5.015 g/cm3. Dielectric constant vs. frequency



Dielectric loss factor versus frequency.

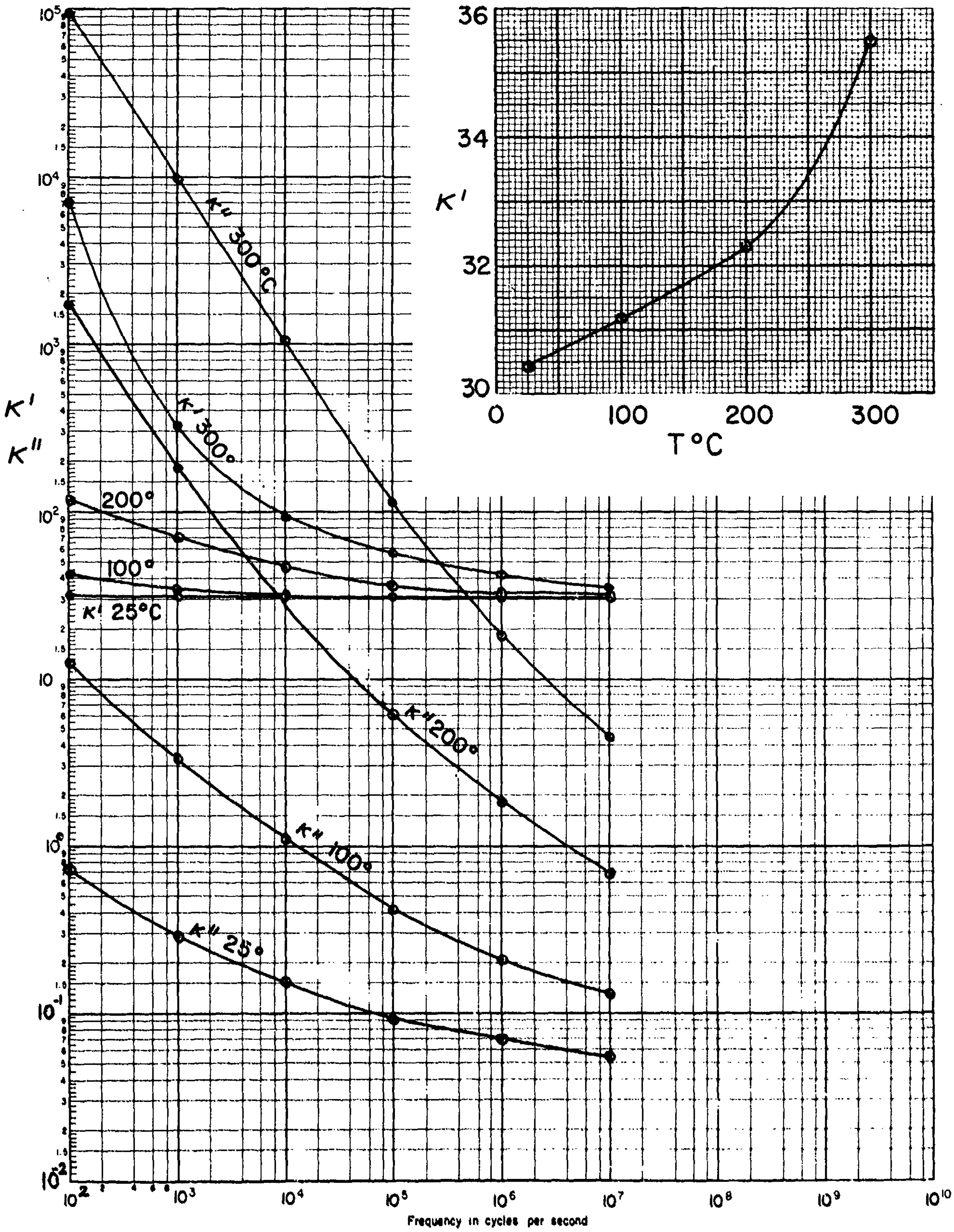
See also p. 121

Zirconium oxide, nuclear grade, conductivity of heavy oxides at 100 Hz vs. 1/T. Activation energies for each approach 1.25 eV.



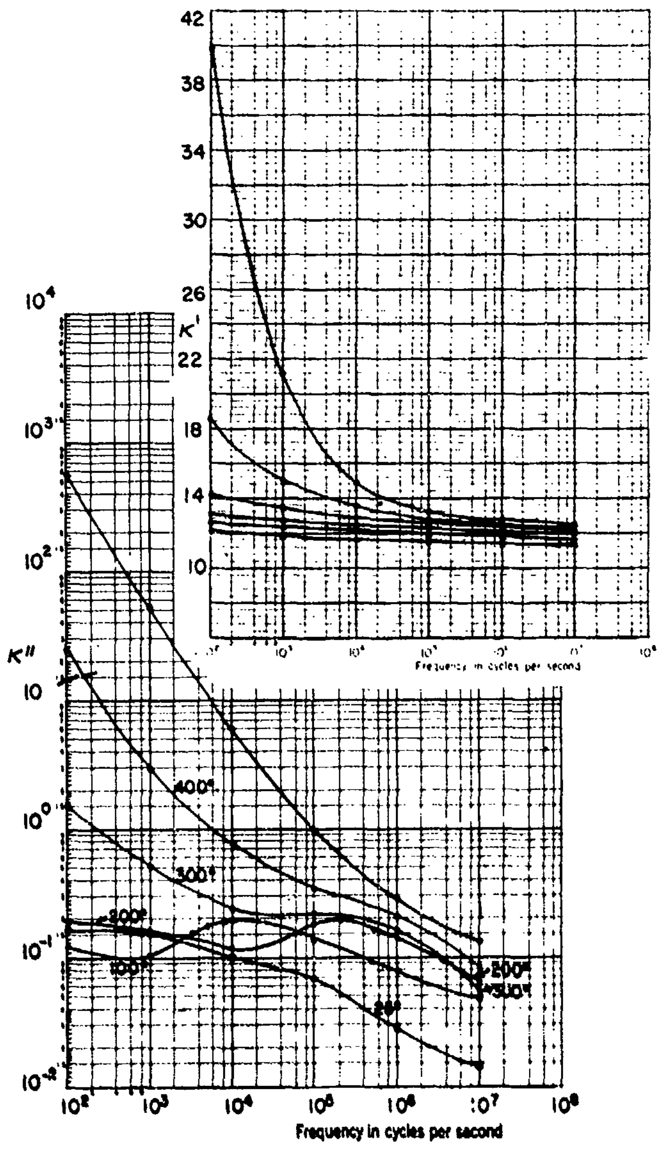
Zirconium oxide, "Zircolite" ceramic

Air Force Materials Laboratory
Wright-Patterson Air Force
Base, Ohio

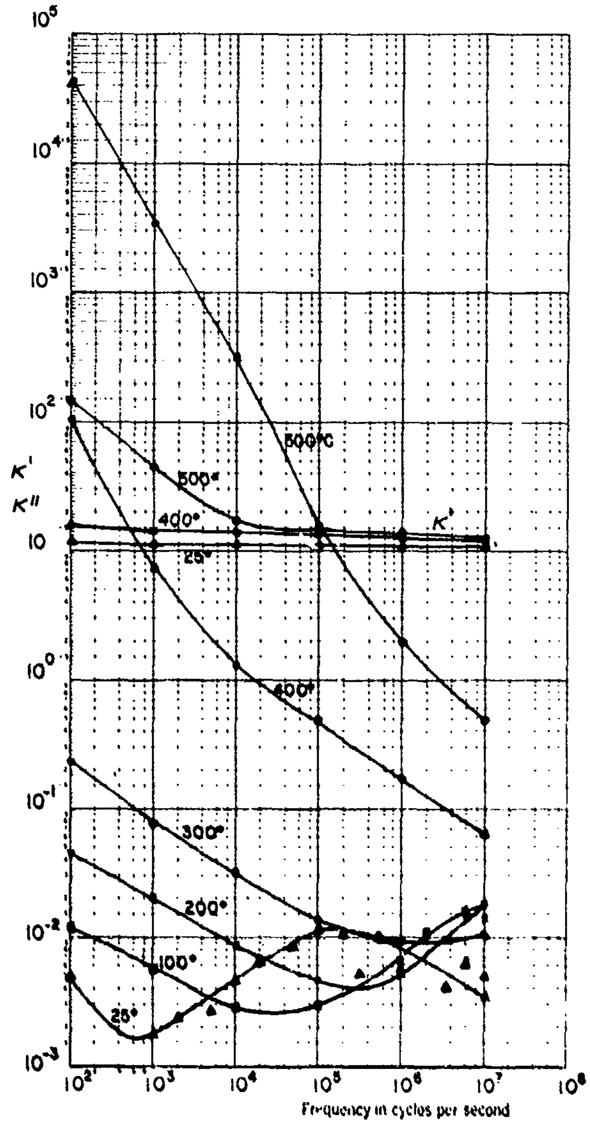


Zirconium silicate (zircon), $ZrSiO_4$,
single crystal, all samples from
one crystal

E || c
Sample 1, run 1,
N_2 to 200°C, air to 500°C,
Ag electrodes



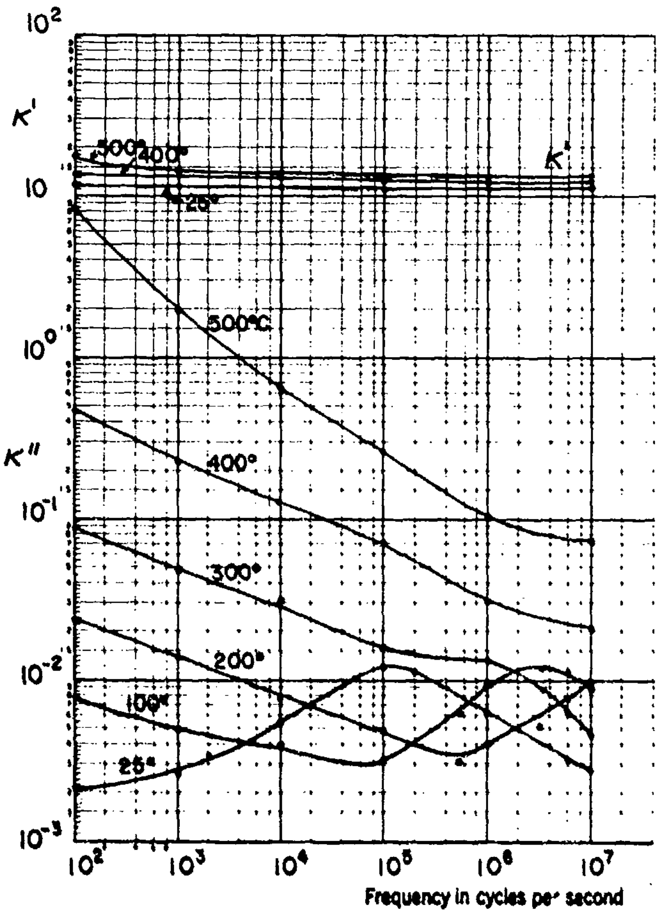
E || c
Sample 2, run 1,
same conditions as for Sample 1



Zircon (cont.)

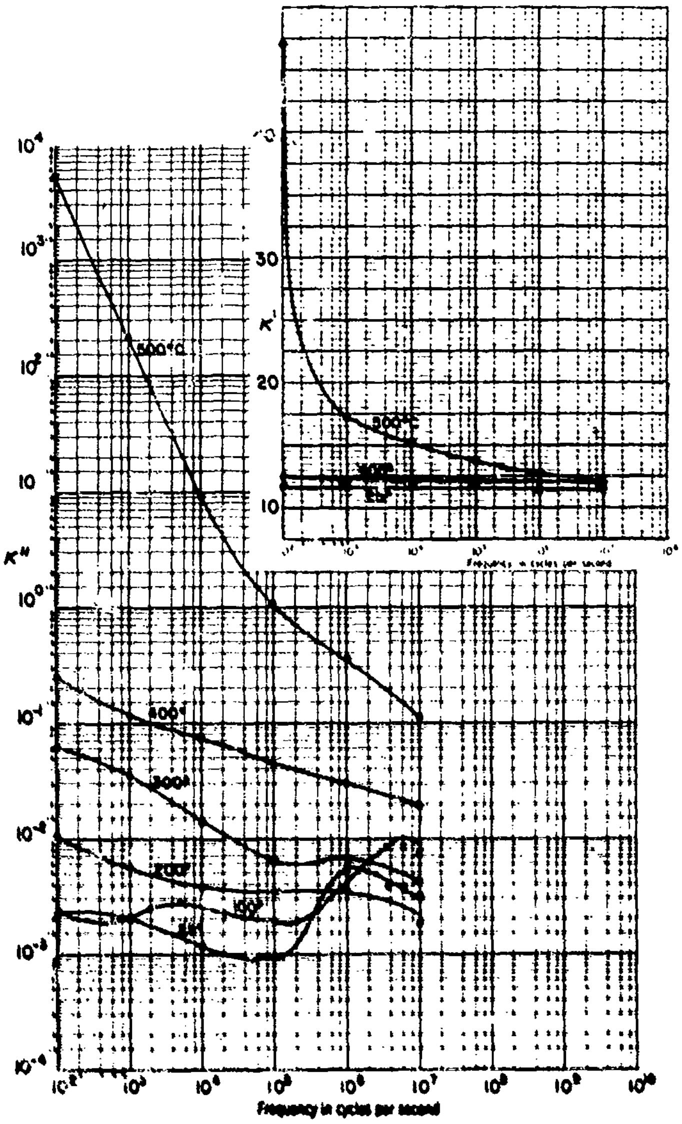
E || c
Sample 2, run 2

Argon atmosphere throughout the run, Ag electrodes



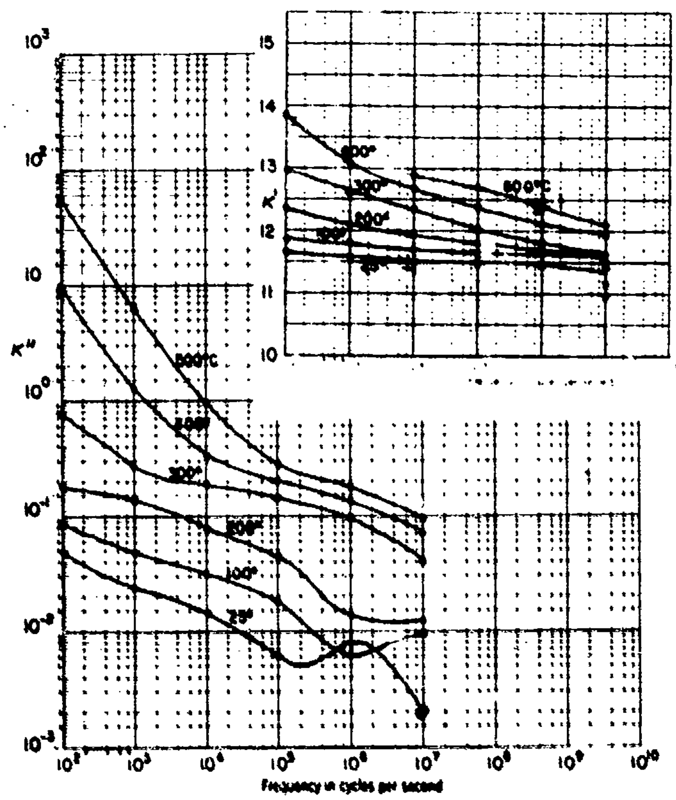
E ⊥ c
Sample 1, run 1

N_2 to 200°C, air to 500°C, Ag electrodes

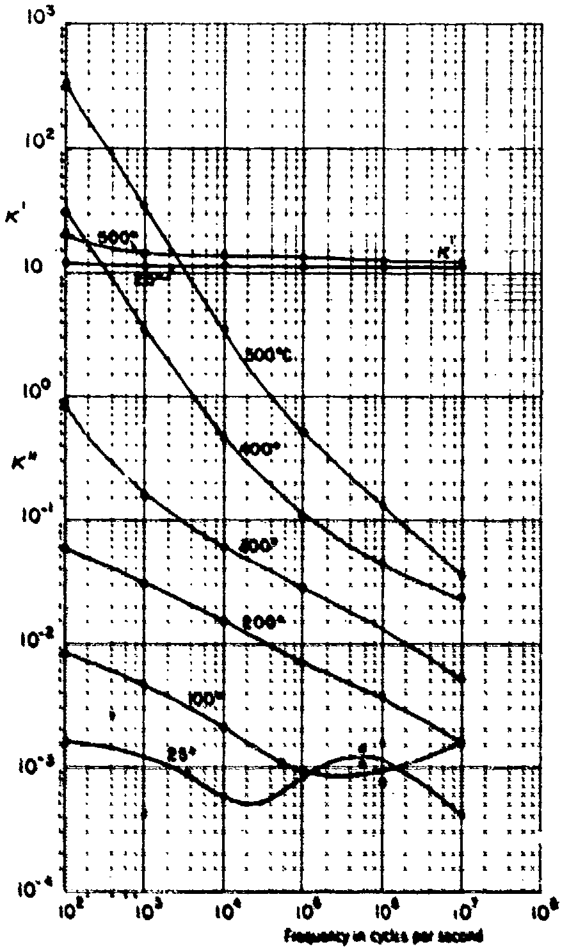


Zircon (cont.)

E ⊥ c
Sample 1, run 2
N_2 to 500°C, Ag electrodes



E ⊥ c
Sample 1, run 3
Air to 500°C, Pt electrodes



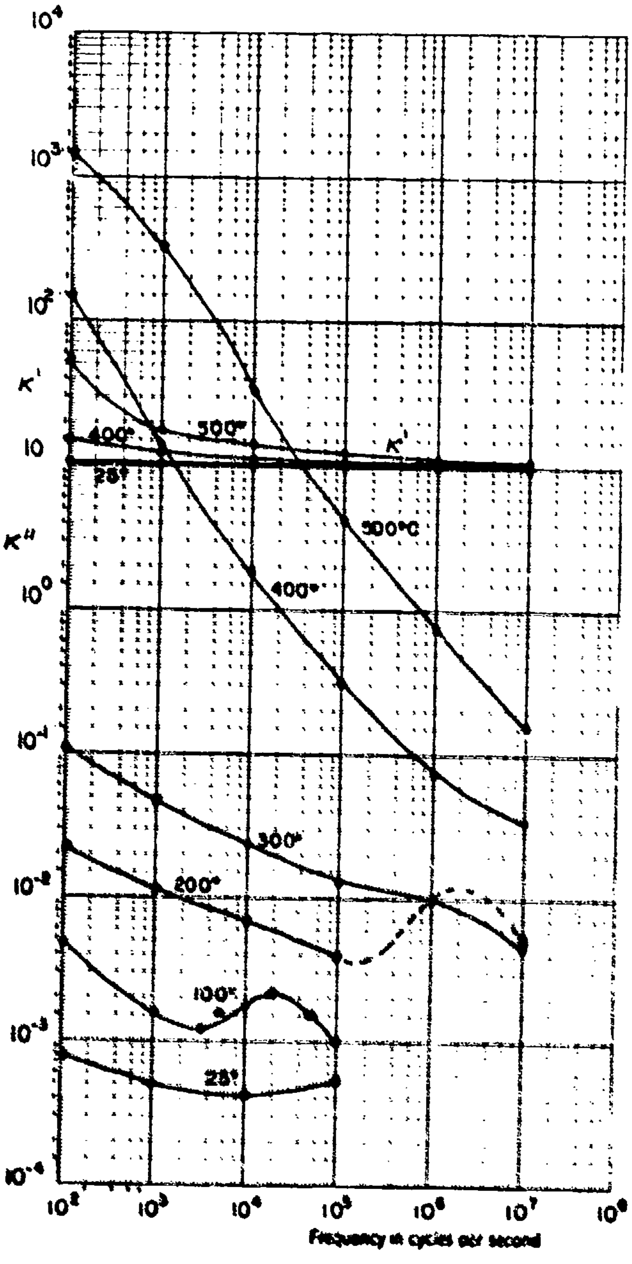
Single-crystal minerals

Apatite

E ⊥ c

Sample 1, run 1, 25°C

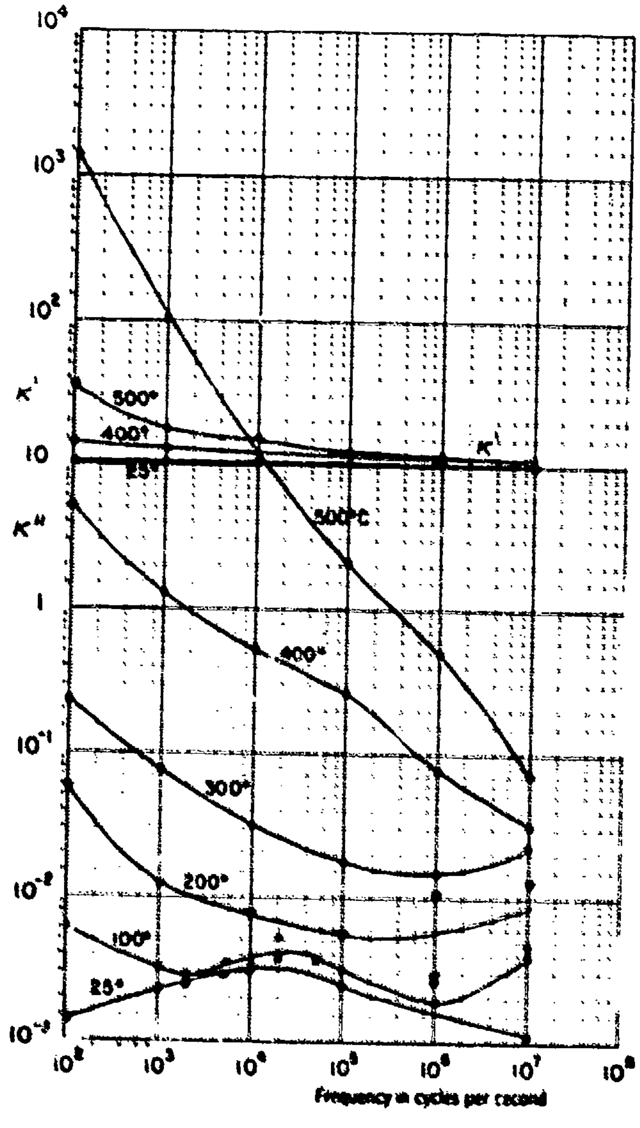
1 MHz, κ' = 10.1



E ⊥ c

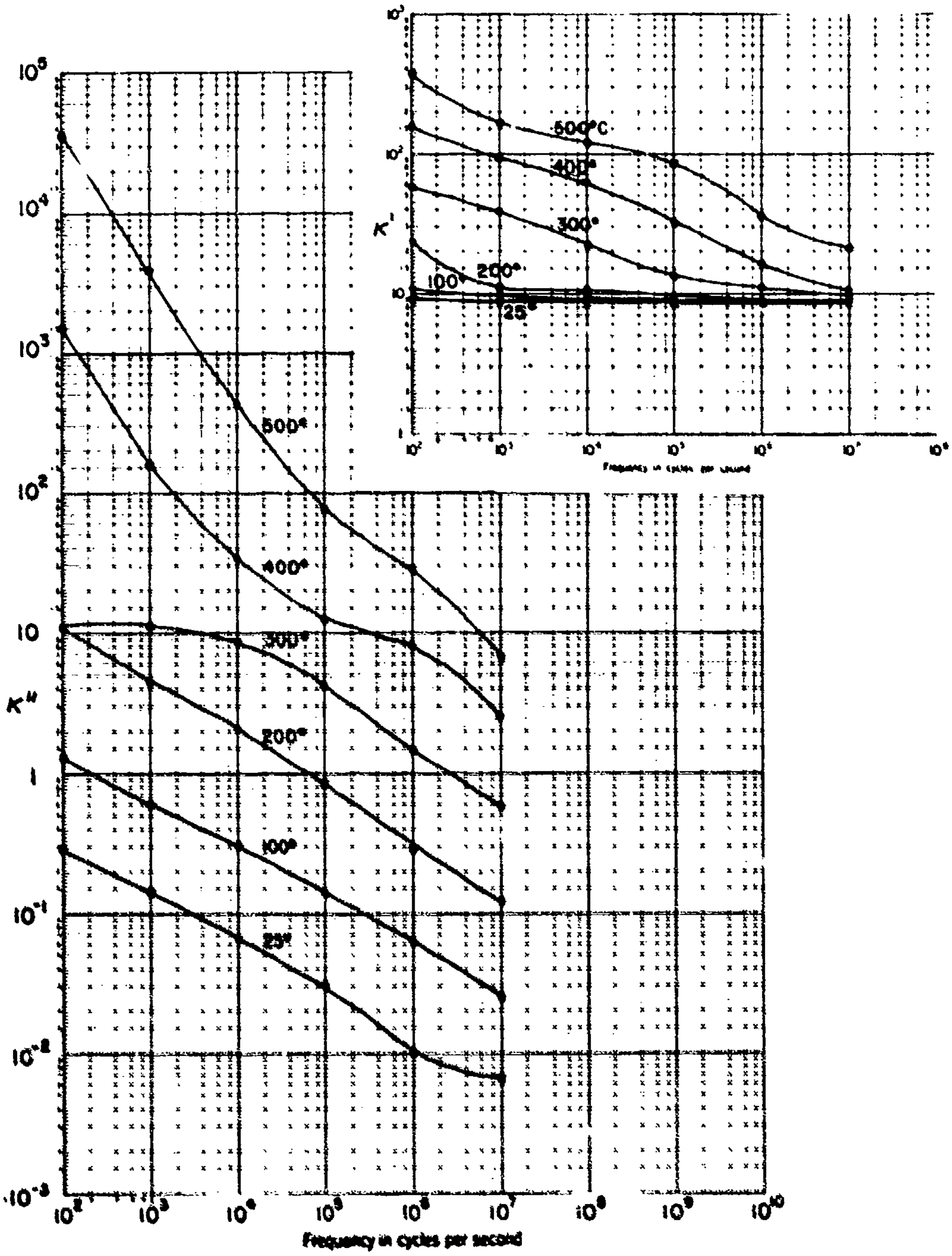
Sample 1, run 2,

repeat of run 1



Apatite (cont.)

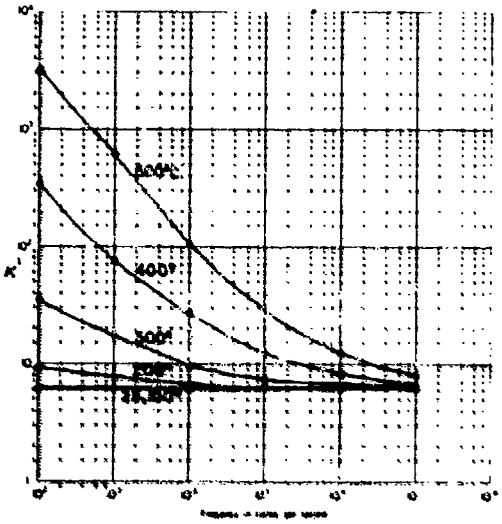
E ‖ c, 25°C, 1 MHz, κ' = 8.58



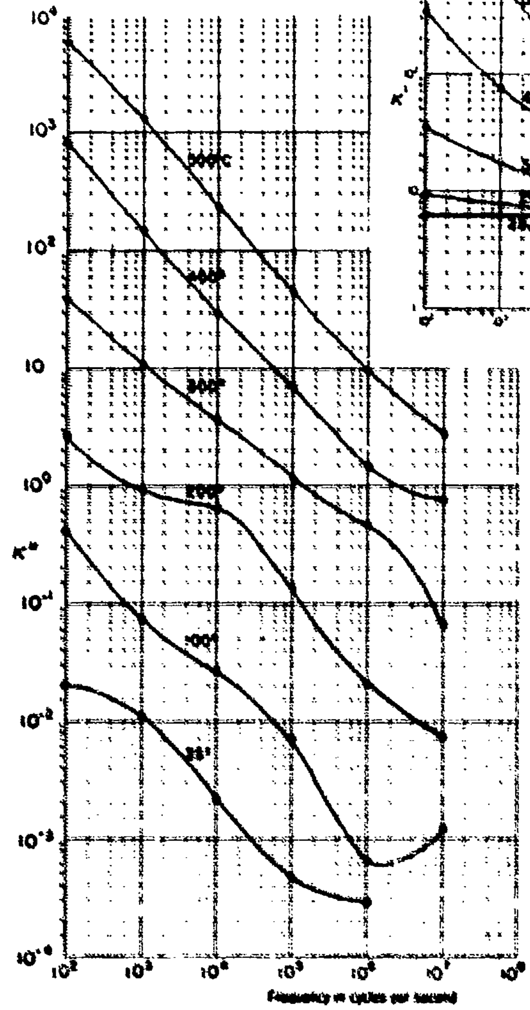
		10^2 Hz	10^3 Hz	10^4 Hz
Astrophyllite				
Unoriented crystal	κ'	15.42	15.17	14.83
	tan δ	0.035	0.021	0.014
Benitoite	κ'	23.8	19.6	19.2
$BaTiS_3O_9$, unoriented cryst.	tan δ	0.374	0.090	0.0195

Beryl

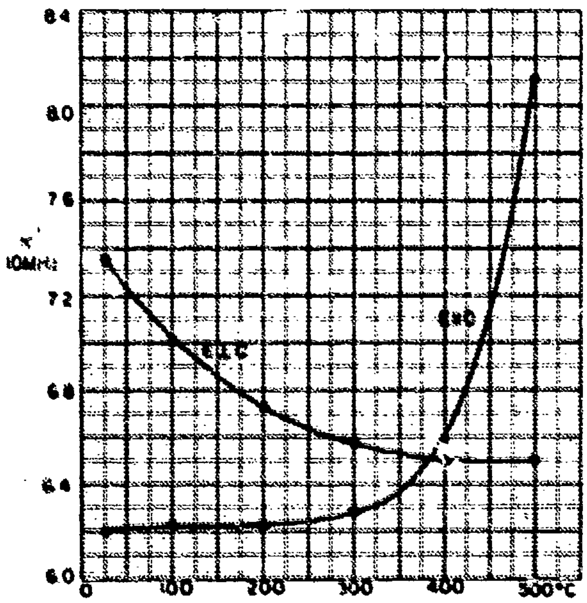
E ‖ c



500°C
400°
300°
200°
25,100°

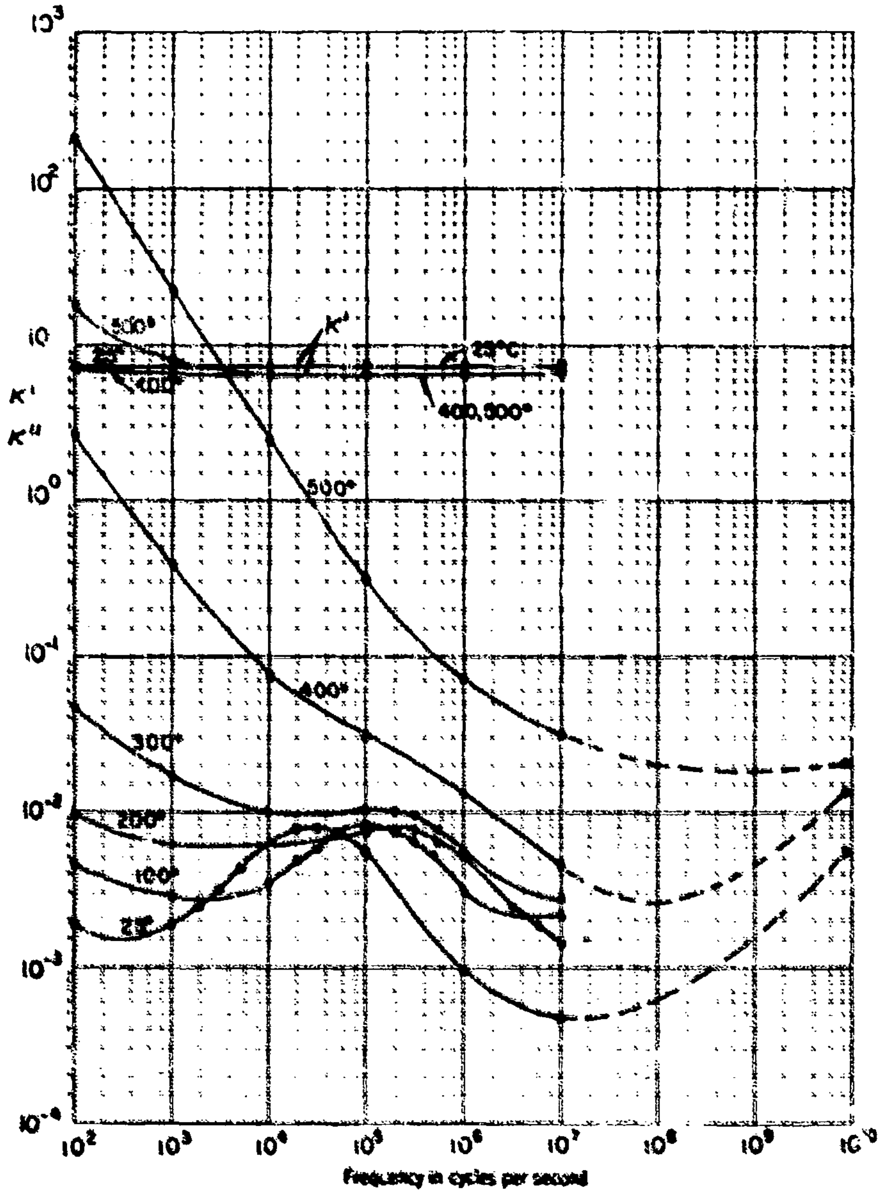


500°C
400°
300°
200°
100°
25°
Frequency in cycles per second



10MHz

Beryl, E ⊥ c

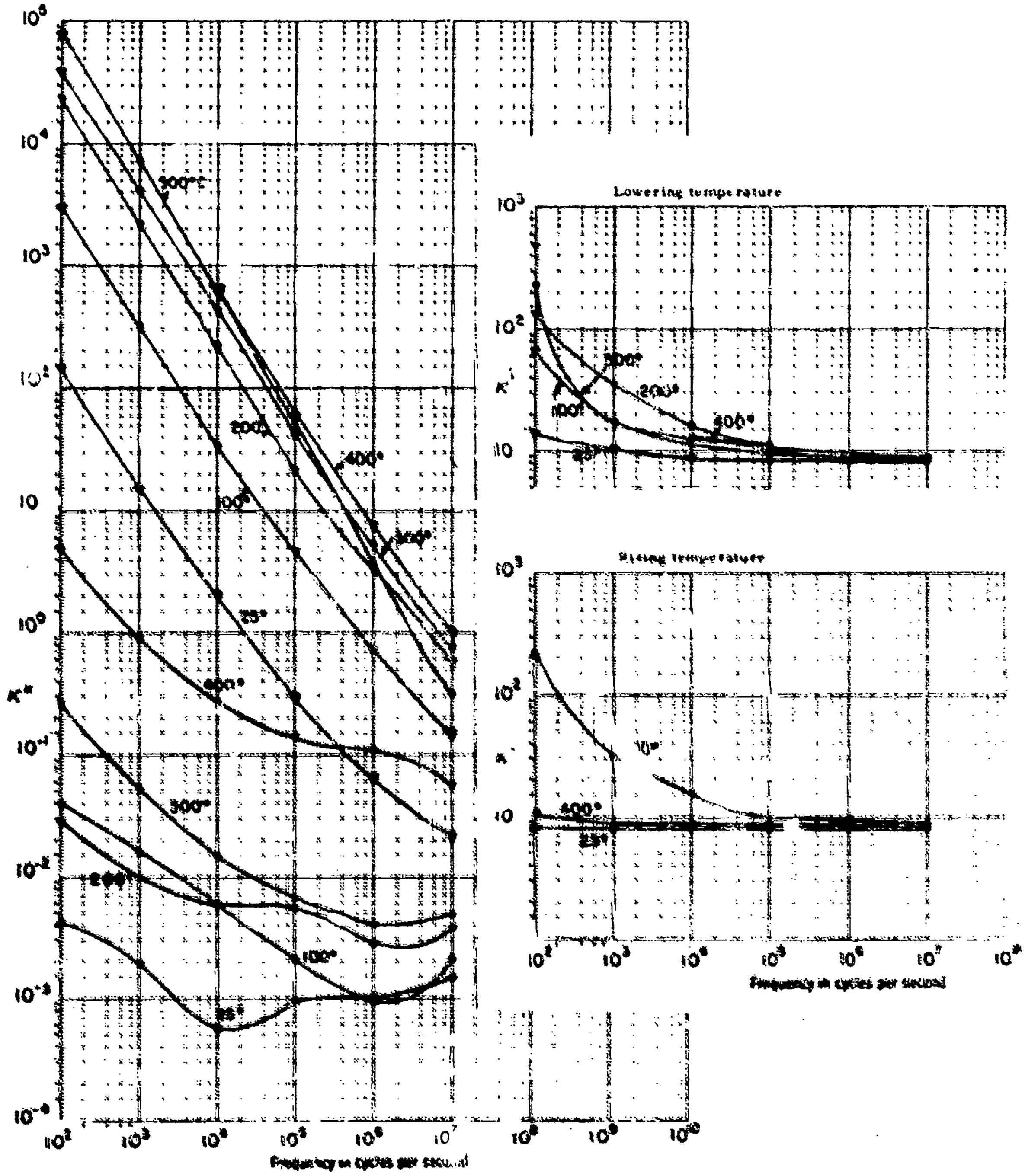


		10^3 Hz	10^4 Hz
Neptunite, $(Na,K)_2(Fe,Mn)(Si,Ti)_5O_{12}$,	κ'	8.33	8.19
data on unoriented crystal	tan δ	0.0335	0.068

Spodumene

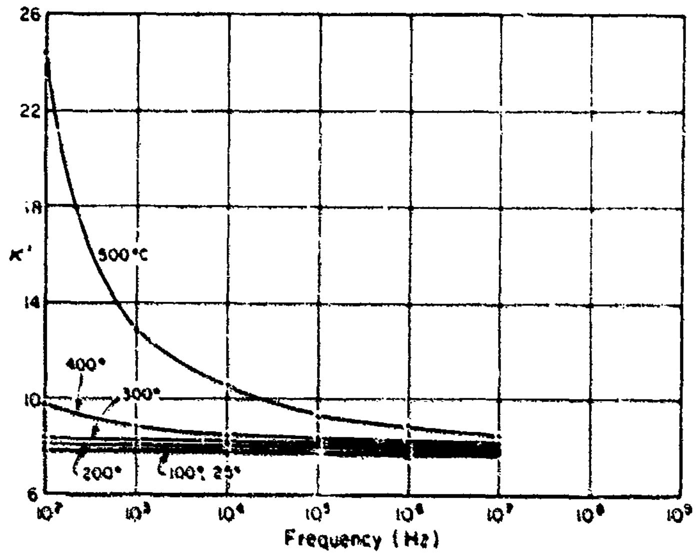
E || a   o rising temperature

∇ lowering temperature

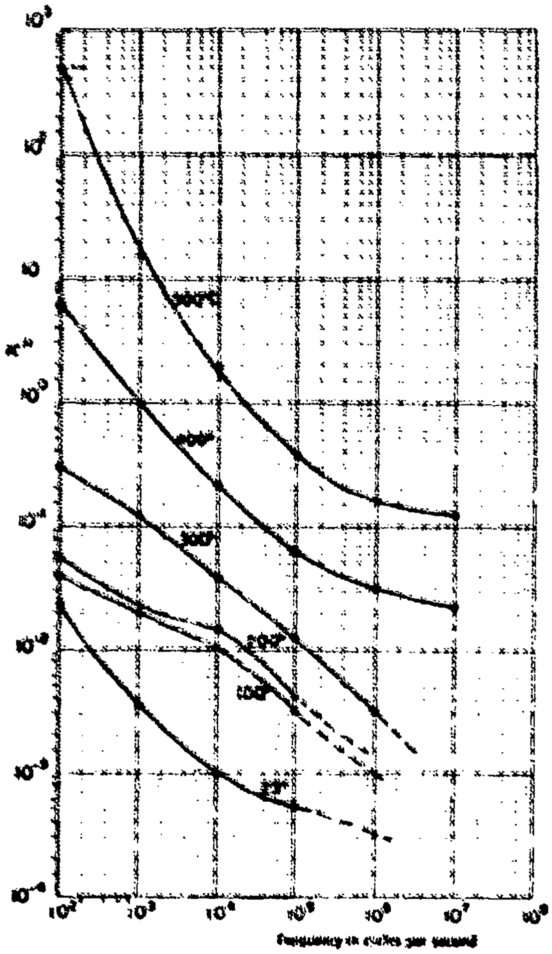


Spodumene (cont.)

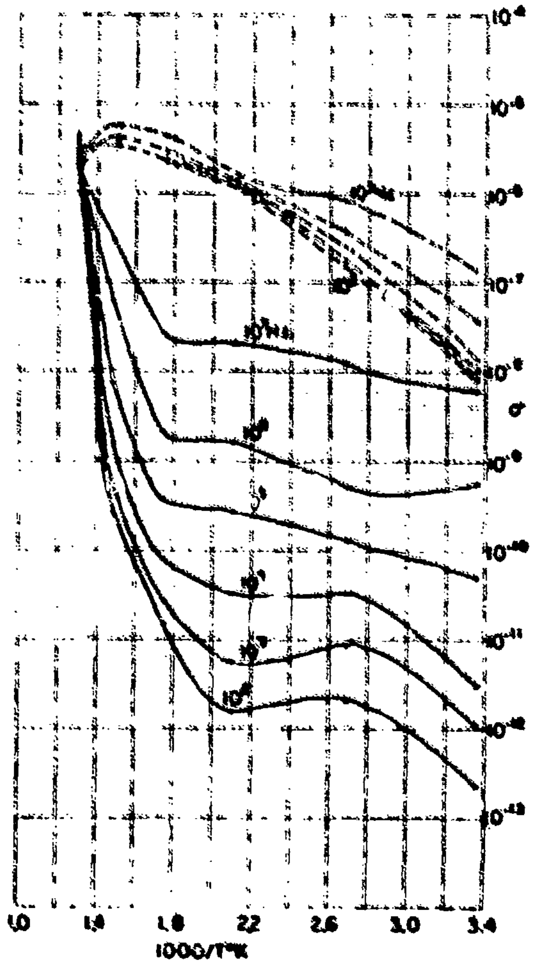
E ∥ b



E ∥ b

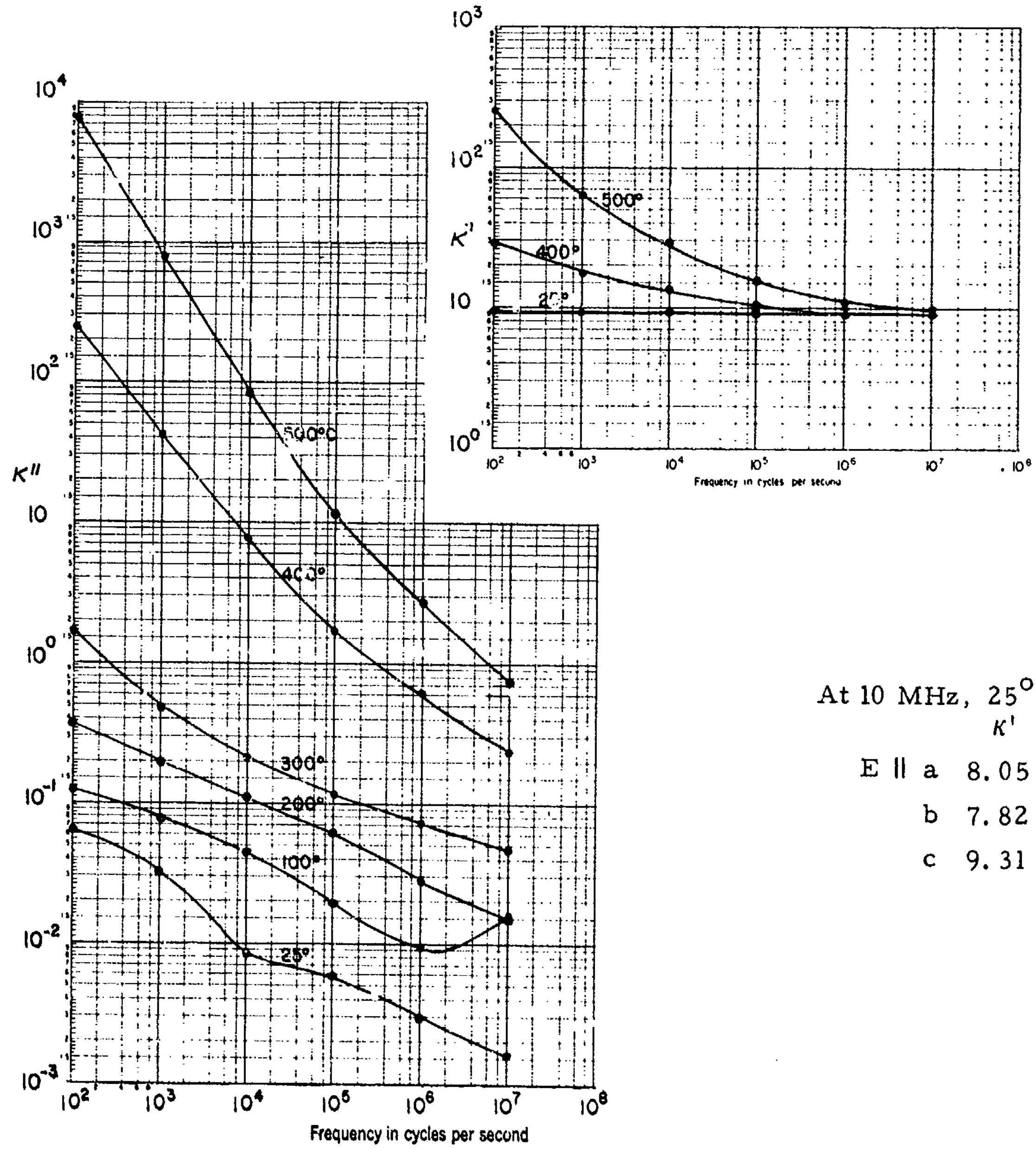


E ∥ a



Spodumene (cont.)

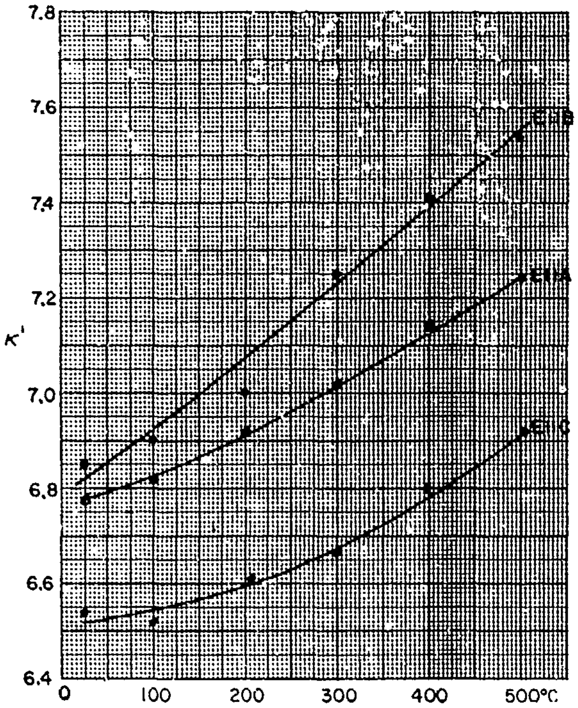
E || c



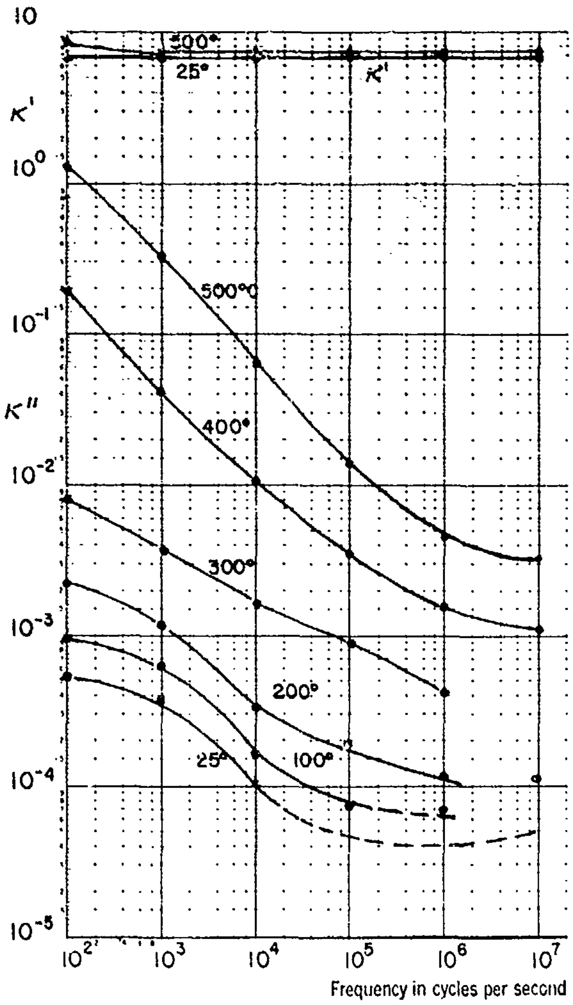
At 10 MHz, 25°C

		K'
E ||	a	8.05
	b	7.82
	c	9.31

κ' at 10 MHz

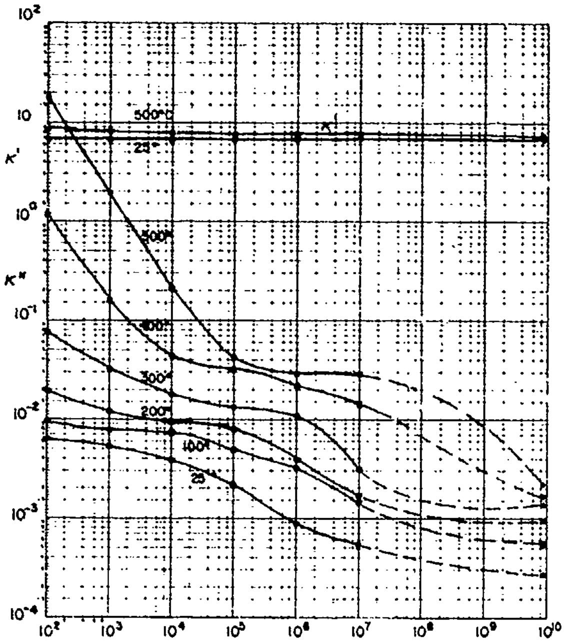

7.8
7.6
7.4
7.2
7.0
6.8
6.6
6.4
κ'
0
100
200
300
400
500°C
E‖B
E‖A
E‖C

E ‖ a

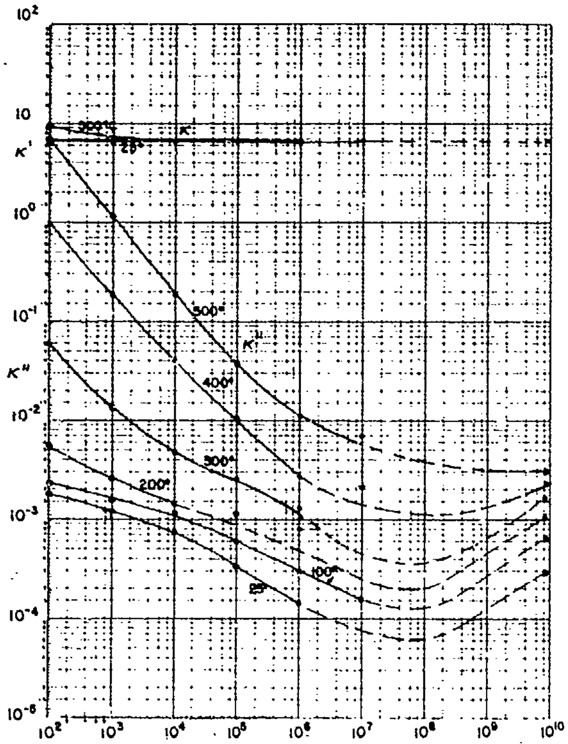

10
κ'
500°
25°
κ'
10^0
10^-1
κ''
10^-2
10^-3
10^-4
10^-5
500°C
400°
300°
200°
100°
25°
10^2
10^3
10^4
10^5
10^6
10^7
Frequency in cycles per second

Topaz (cont.)

E || b

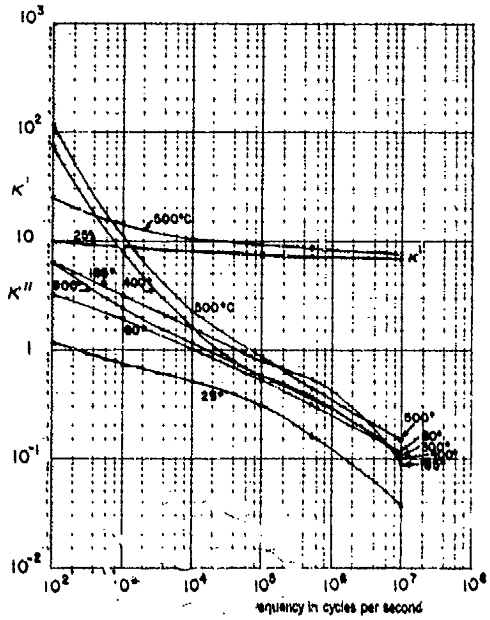


E || c

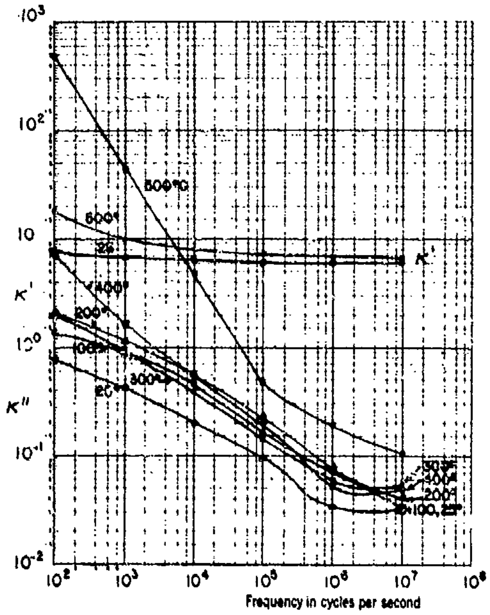


Tourmaline

E ⊥ c, piezoelectrically active at 1 MHz



E || c



Crushed minerals

Halite (rock-like pieces of porous salt), at 50% R.H., 25°C, 14 GHz

Sample	κ'	tan δ	Density (g/cm^3)
1, surface	4.52 - 4.63	.0056 - .0057	1.808
2, "	4.68 - 4.82	.0106 - .0103	1.861
3, "	3.81 - 3.83	.0127 - .0109	1.565
4, "	3.95 - 4.00	.0104 - .0134	1.670
5, 1' down	3.69 - 3.94	.0198 - .0125	1.500
6, "	3.25 - 3.50	.0077 - .0113	1.422
7, 3' "	4.17 - 4.18	.036 - .046	1.646
7, dried	4.12 - 4.19	.0193 - .0206	1.640

Limonite, crushed, density 1.733 g/cm^3

	10^9 Hz		3×10^9	
T°C	κ'	tan δ	κ'	tan δ
25	4.17	.0108	3.73	.046
475	3.65	.0134	3.63	.0193
404	3.62	.0076	3.60	.0113
325	3.61	.0057	3.58	.0084
250	3.61	.0048	3.57	.0073
185	3.60	.0045	3.56	.0064
107	3.58	.0047	3.55	.0059
22	3.56	.0057	3.53	.0055

Sample in equilibrium with room humidity approx. 50%.

Harvard College Observatory

Limonite, 8.52 GHz

Sample 1, coarse, 25°C
κ' = 3.95 - 4.01 depending on rotation
tan δ = 0.18 - 0.059

Sample 2, fine, 25°C

tan δ = 0.0122 - 0.0127

Sample 3

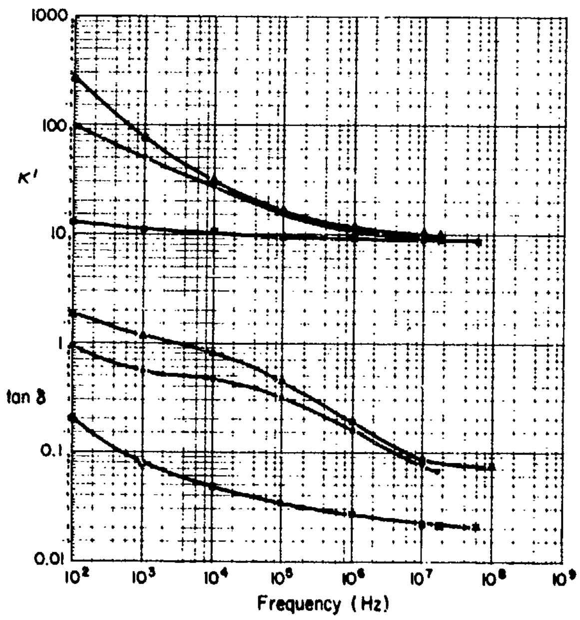
T°C	κ'	tan δ
25	3.82	.0012
510	3.60	.0085
400	3.55	.0047
300	3.52	.0039
200	3.50	.0042
100	3.48	.0043
25	3.49	.0043

Magnesite, crushed powder, hard-packed
25°C, 50% R.H., 8.52 GHz, κ' = 3.29, tan δ = .0054 - .0059, density 1.11 g/cm^3

Quartz powder, 8.52 GHz, pre-dried in oven at 100°C, density 1.22 g/cm^3

T°K	κ'	tan δ
80	2.446	.0021
200	2.460	.0027
300	2.472	.0028
400	2.483	.0027
500	2.495	.0031
600	2.497	.0035

Hawaiian high-density basalt



● % H_2O on dry weight basis 0.358
% H_2O on dry volume basis 0.956
density 2.6756 g/cm^3

■ Dry after 3 days in oven at 105°C
density 2.669 g/cm^3

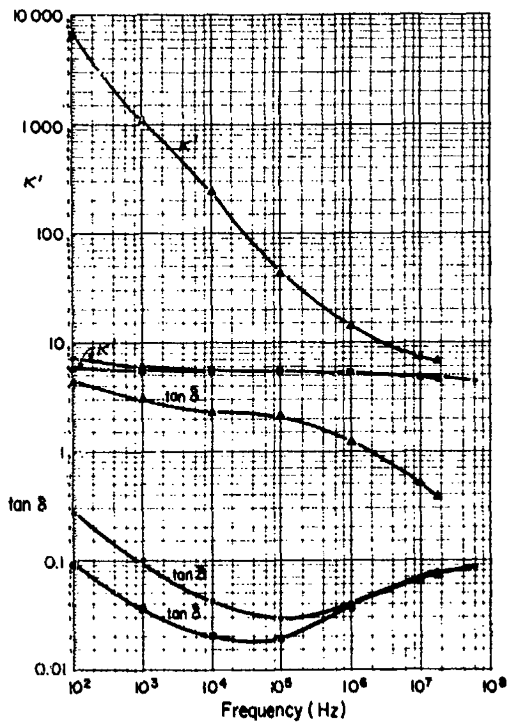
▲ % H_2O on dry weight basis 0.377
% H_2O on dry volume basis 1.005
density 2.677 g/cm^3

Hawaiian high-density basalt
50% relative humidity

Density 2.717 g/cm^3

	Sample 1	Sample 2	Sample 3	Sample 3	Sample 3	Sample 4
Freq. (Hz)	3×10^8	10^7	3×10^8	10^9	3×10^9	8.5×10^9
κ	8.36	9.90	9.30	9.08	8.85	8.40
tan δ	.043	.080	.034	.033	.037	.04
μ'/μ_o	1.174	1.17	1.113	1.10	1.08	1.01
tan δ_m	.0077	<.002	.0075	.026	.072	.06

Hawaiian low-density basalt



● % H_2O on dry weight basis 0.441
% H_2O on dry volume basis 0.0617
density 1.401 g/cm^3

■ Dry (after 3 days in oven at 105°C
density 1.400 g/cm^3

▲ % H_2O on dry weight basis 2.71
% H_2O on dry volume basis 3.79
density 1.438 g/cm^3

Hawaiian low-density basalt
50% relative humidity

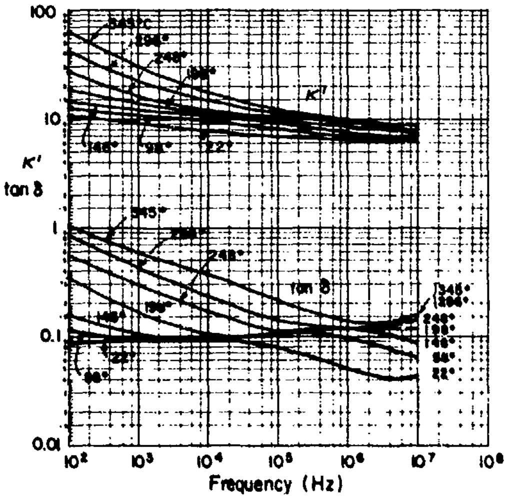
Freq. (Hz)	10^7	3×10^8	10^9	3×10^9
κ	4.9	3.74	3.51	3.30
tan δ	.068	.085	.0481	.053
μ'/μ_o	1.047	1.047	1.040	1.035
tan δ_m	<.002	.0040	.002	.002

Hawaiian deep-ocean basalt
No change after heating to 200°C

Freq. (Hz)	10^5	10^6	10^7	8.5×10^9
κ	188	153	124	10.2
tan δ	93.5	11.6	.146	.560
ρ	1025	1015	995	36.9

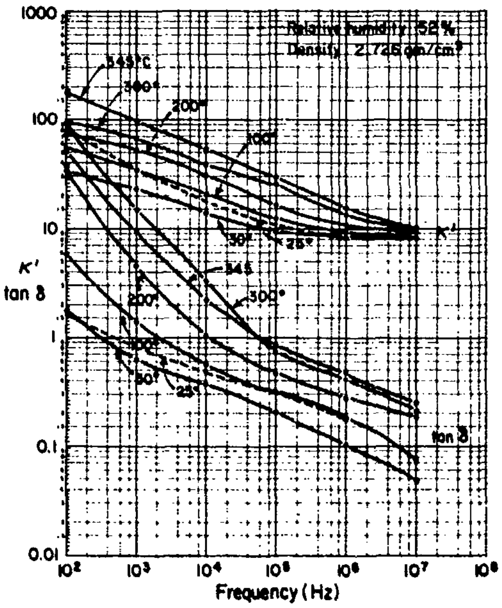
Quincy granite

Density 2.631 g/cm^3
Temp. run in dry N_2



Virginia granite or marble

Temperature run in dry N_2



Quincy granite

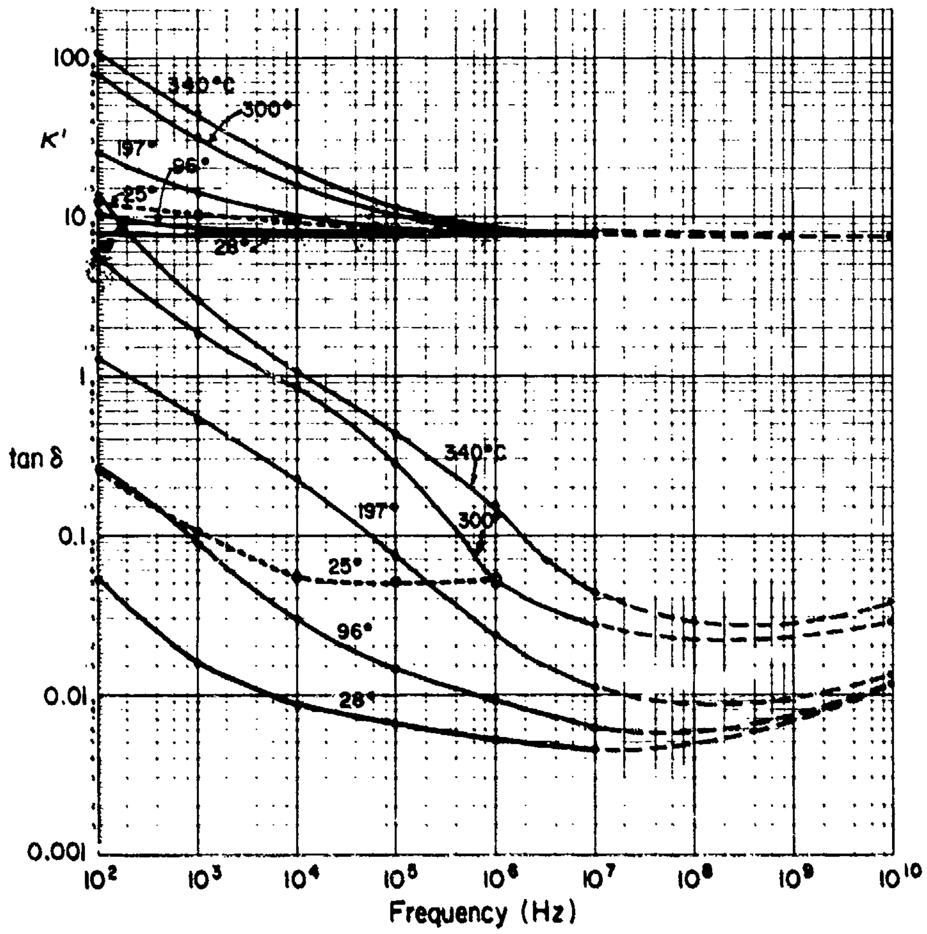
T°C		10^2 Hz	10^3 Hz	10^4 Hz	10^5 Hz
25	κ'	10.5	9.26	8 01	2.06
	tan δ	0.0796	0.0875	0.0875	0.0705
	σ	4.64×10^{-11}	4.5×10^{-10}	3.9×10^{-10}	2.76×10^{-8}
200	κ'	15.4	12 47	11.07	9.78
	tan δ	0 21	0.121	0.088	0.090
	σ	$1\ 797 \times 10^{-10}$	8.37×10^{-10}	5.40×10^{-9}	4.88×10^{-8}
400	κ'	64.5	32.9	19.42	12.86
	tan δ	1 02	0.60	0.374	0.252
	σ	3.65×10^{-9}	1.097×10^{-8}	4.03×10^{-8}	1.797×10^{-7}
600	κ'	293	106	42.5	22.0
	tan δ	6 85	2.31	1.03	0 54
	σ	$1\ 114 \times 10^{-7}$	$1\ 36 \times 10^{-9}$	2.43×10^{-7}	6.60×10^{-7}
800	κ'	4395	238	84	37.4
	tan δ	14 4	9.65	3.05	1 11
	σ	$1\ 116 \times 10^{-6}$	1.275×10^{-6}	1.423×10^{-6}	2.30×10^{-6}
1000	κ'		47000	6100	710
	tan		14.0	12 6	12 4
	σ		$3\ 65 \times 10^{-4}$	$4\ 26 \times 10^{-4}$	4.89×10^{-4}

	1 kHz	
T°C	κ'	σ
26	9.26	4.50×10^{-10}
69	10.3	4.58
105	10.9	4.64
147	11.5	5.31
204	12.51	8.61×10^{-10}
251	14.87	1.85×10^{-9}
305	19.3	3.38×10^{-9}
345	23.4	5.51×10^{-9}
400	32.9	1.09×10^{-8}
466	34.4	9.5×10^{-8}
553	81.3	9.34×10^{-8}
601	106	1.36×10^{-9}
700	172	4.25×10^{-7}
806	243	1.313×10^{-6}
874	26,800	$1\ 84 \times 10^{-4}$
996	45,900	$3\ 57 \times 10^{-4}$

Virginia Greenstone

Density 2.936 g/cm^3, temperature run in dry N_2

(-----) R. H. 52%



Limestone, from Lucerne Valley — Raytheon

50% R. H., 25°C, 14 GHz

Sample	K'	tan δ	Density
1	8.21 - 8.45	.0038 - .0080	2.667
2	8.62 - 8.64	.0178 - .0189	2.646

Synthetic basalt and lunar rocks, Apollo 11 and 12, see:

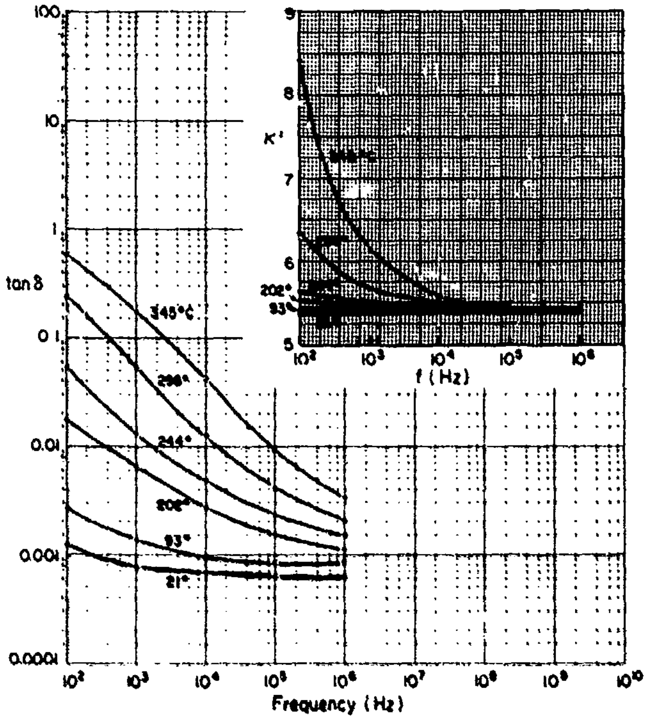
D.H. Chung, W. B. Westphal, and G. Simmons, "Dielectric Properties of Apollo 11 Lunar Samples and their Comparison with Earth Materials," J. Geophys. Res. 75, 6524-6531 (1970).

D. H. Chung, W. B. Westphal, and G. Simmons, "Dielectric Properties of Apollo 12 Lunar Samples," a paper (T64c) presented at the 1970 Am. Geophys. Union Meeting, Washington D.C., April 23, 1970.

D. H. Chung, W. B. Westphal, and G. Simmons, Dielectric Behavior of Lunar Samples: Electromagnetic Probing of the Lunar Interior," Proc. Second Lunar Sci. Conf., Vol. 3, MIT Press, 1971, pp. 2381-2390.

Rhyolite

Density 2.655 g/cm^3, temperature run in dry N_2

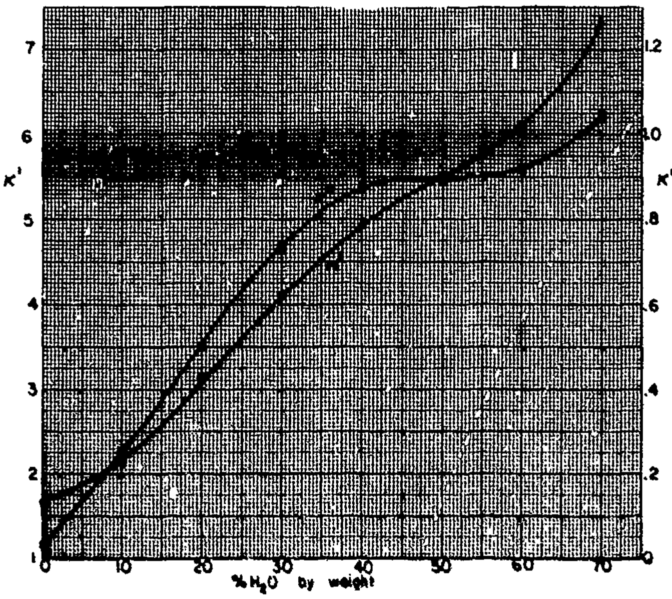


Sandstone, almond, oil-bearing as cored, 25°C **Raytheon**

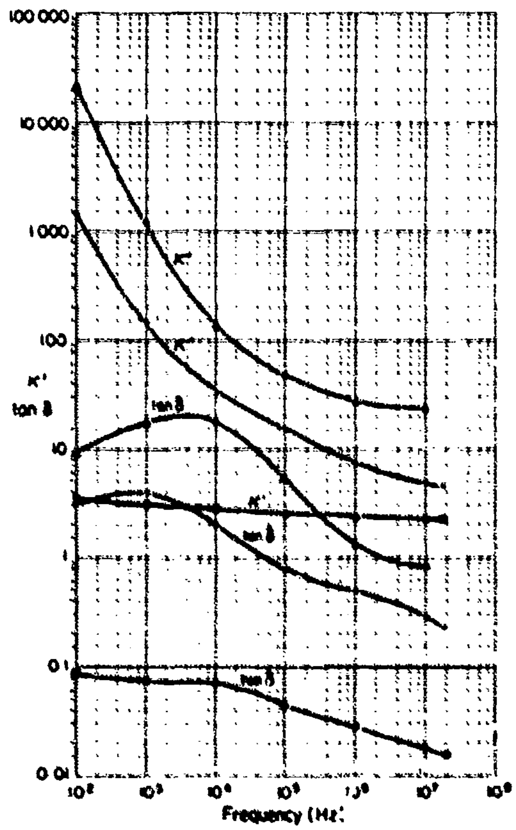
Sample		Frequency in MHz: 1	3	10	60	100
1	κ'	5.64	5.23	4.90	4.55	4.50
	tan δ	0.131	0.104	0.084	0.059	0.049
2	κ'	6.13	6.09	6.07	6.06	6.06
	tan δ	0.0100	0.0084	0.0059	0.0047	0.0051
3	κ'	6.05	6.04	6.01	5.91	5.87
	tan δ	0.0068	0.0079	0.00855	0.0095	0.0097
4	κ'	5.33	5.08	4.92	4.75	4.73
	tan δ	0.060	0.057	0.051	0.036	0.027
5	κ'	5.40	5.16	4.93	4.68	4.61
	tan δ	0.080	0.068	0.058	0.042	0.032
6	κ'	22.9	11.24	9.20	6.60	6.20
	tan δ	1.88	1.39	0.68	0.338	0.29
7	κ'	6.15	6.12	6.10	6.04	6.00
	tan δ	0.0088	0.0093	0.0096	0.0102	0.0105

Soils

Fullers Earth, at 8.52 GHz



Hawaian



● % H_2O on weight basis
% H_2O on volume basis
Density 0.8634 g/cm^3

■ Dry after 3 days in oven at 105°C
Density .7627 g/cm^3

▲ % H_2O on dry weight basis = 72.27
% H_2O on volume basis + 50.60
Density 1.2133 g/cm^3

Soils

Hawaian soil saturated with distilled H_2O

% H_2O on dry weight basis = 127.5

% H_2O on volume basis = 63.0

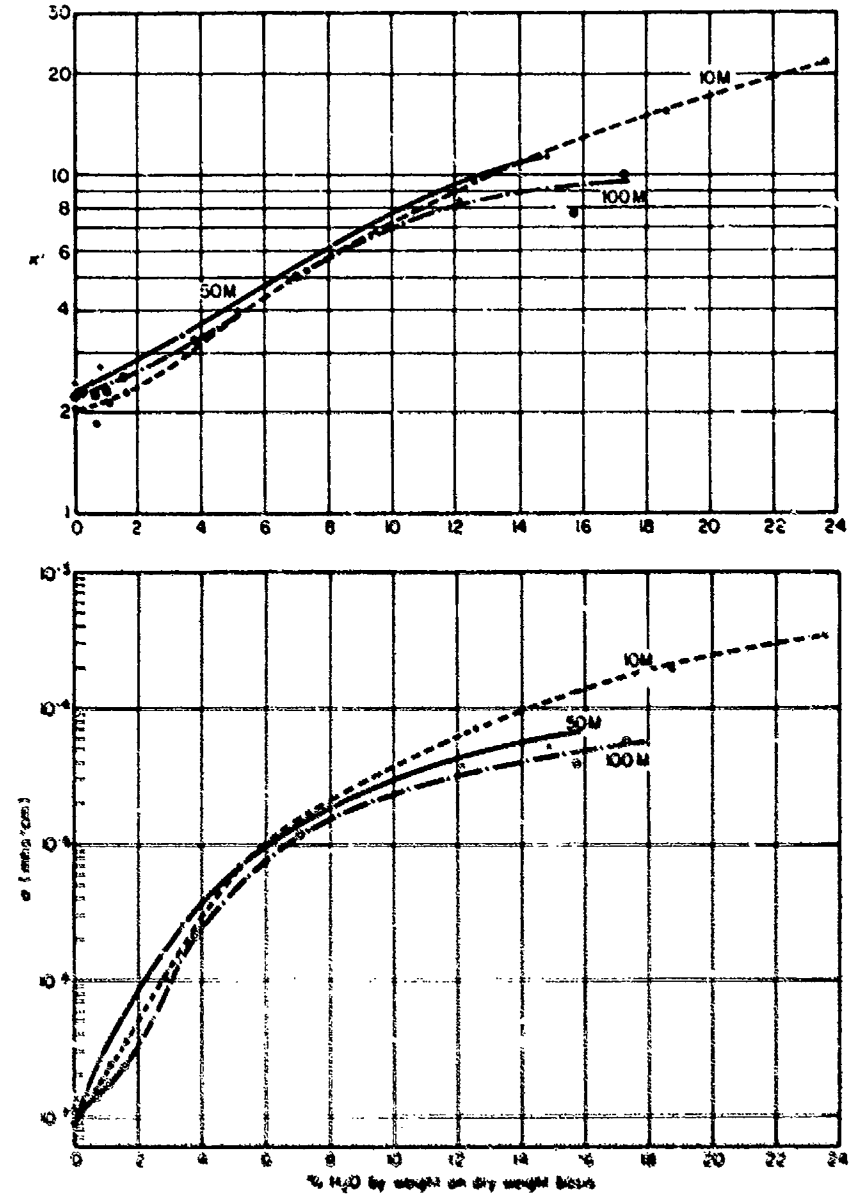
Density 1.303 g/cm^3

Freq. (Hz)	10^3	10^4	10^5	10^6	9.5×10^6	7×10^7
κ	29,700	988	230	1295	81.5	64.2
tan δ	135	43.9	20.05	3.32	.776	.185

Hawaian soil with approximately 25% H_2O on dry weight basis. Density $\cong$ .88 g/cm^3.

Freq. (Hz)	10^2	10^3	10^4	10^5	10^6	10^7	3×10^8	1×10^9	3×10^9	8.5×10^9
κ	10560	940	68.0	21.66	12.04	6.88	5.12	4.90	4.45	3.97
tan δ	2.30	4.43	7.25	2.67	.827	.389	.105	.079	.81	.135

Mass. loams, at 10 MHz, 25°C



Desert sand (Raytheon)

15% R. H., 25°C, 14 GHz

κ' = 2.88

$\tan \delta = 0.0115$

Density = 1 633 g/cm^3

Miscellaneous Inorganics

Sands

Sample	Condition		10^8	$3x10^8$	10^9
Holliston	As received	κ	2.73	2.70	2.67
sand	d = 1.54	tan δ	0.0044	0.00278	0.00217
		% H_2O	0.09	0.06	0.06
	Dry	κ	2.70	2.69	2.67
	d = 1.54	tan δ	0.0022	0.00235	0.0017
	1% H_2O	κ	3.25	3.22	3.12
	d = 1.53	tan δ	0.0084	0.059	0.062
	3% H_2O	κ	3.40	3.35	3.30
	d = 1.39	tan δ	0.0224	0.0930	0.120
	10% H_2O	κ	7.25	7.15	6.85
	d = 1.45	tan δ	0.056	0.054	0.056
	93% RH	κ	2.87	2.85	2.81*
	d = 1.58	tan δ	0.006	0.020	0.063*
Slatterville	As received		2.84	2.82	2.80
sand No. 60	d = 1.60		0.0070	0.0033	0.0033
	Dry		2.82	2.80	2.78
	d = 1.60		0.0038	0.0024	0.0016
	1% H_2O		2.80	2.72	2.67
	d = 1.53		0.032	0.040	0.50
	3% H_2O		3.60	3.51	3.19
	d = 1.48		0.047	0.061	0.089
	10% H_2O		7.50	7.35	7.06
	d = 1.54		0.090	0.109	0.081
	93% RH		2.92	2.90	2.84
	d = 1.60		0.004	0.0106	0.0564

* % H_2O = 0.385

Miscellaneous Inorganics
Ices, glacial

Dielectric Constants

Sample, Source	Density (g/cm^3)	Temp. ($^o/C$)	Frequency in MHz: 110*	150	300	500	1000	2700
Dartmouth		-1	3.22	3.21	3.20	3.20	3.20	3.201
Firm ice		5	3.21	3.20	3.20	3.20	3.20	3.195
No. 12		10	3.20	3.19	3.19	3.19	3.19	3.188
		20	3.18	3.18	3.18	3.18	3.18	3.175
	0.898	30	3.17	3.16	3.16	3.16	3.16	3.163
		40	3.15	3.15	3.15	3.15	3.15	3.151
		50	3.14	3.14	3.14	3.14	3.14	3.139
		60	3.13	3.13	3.13	3.13	3.13	3.129
Dartmouth		-1	3.41	3.38	3.34	3.31	3.28	
Sea ice		5	3.33	3.31	3.29	3.27	3.26	
No. 14		10	3.28	3.26	3.25	3.24	3.24	
		15	3.26	3.24	3.24	3.23	3.22	
		20	3.23	3.22	3.21	3.20	3.20	3.197
		25	3.22	3.21	3.20	3.19	3.19	3.184
	0.917	30	3.21	3.20	3.19	3.18	3.17	3.173
		40	3.19	3.18	3.17	3.16	3.16	3.159
		50	3.18	3.17	3.16	3.15	3.15	3.144
		60	3.15	3.15	3.14	3.14	3.14	3.133
Tuto		-1	3.22	3.21	3.20	3.20	3.20	3.197
Tunnel		5	3.20	3.19	3.19	3.19	3.19	3.189
		10	3.19	3.18	3.18	3.18	3.18	3.182
		20	3.17	3.17	3.17	3.17	3.17	3.170
	0.902	30	3.16	3.16	3.16	3.16	3.16	3.159
		40	3.15	3.15	3.15	3.15	3.15	3.149
		50	3.14	3.14	3.14	3.14	3.14	3.138
		60	3.13	3.13	3.13	3.13	3.13	3.129
Little		-1	3.09	3.08	3.07	3.07	3.07	3.065
America		5	3.07	3.06	3.06	3.06	3.06	3.057
		10	3.06	3.05	3.05	3.05	3.05	3.050
		20	3.04	3.04	3.04	3.04	3.04	3.038
	0.881	30	3.03	3.03	3.03	3.03	3.03	3.025
		40	3.01	3.01	3.01	3.01	3.01	3.012
		50	3.00	3.00	3.00	3.00	3.00	3.000
Arctic		-1	2.90					2.880
		5	2.89					2.875
		10	2.88					2.870
		20	2.86					2.861
	0.835	30	2.85	2.85	2.85	2.85	2.85	2.852
		40	2.85	2.85	2.85	2.84	2.84	2.844
		50	2.84	2.84	2.84	2.84	2.84	2.835
		60	2.83	2.83	2.83	2.83	2.83	2.827

* 110 MHz values are extrapolated, not measured.

Ices (cont)

Loss Tangent

Frequency in MHz

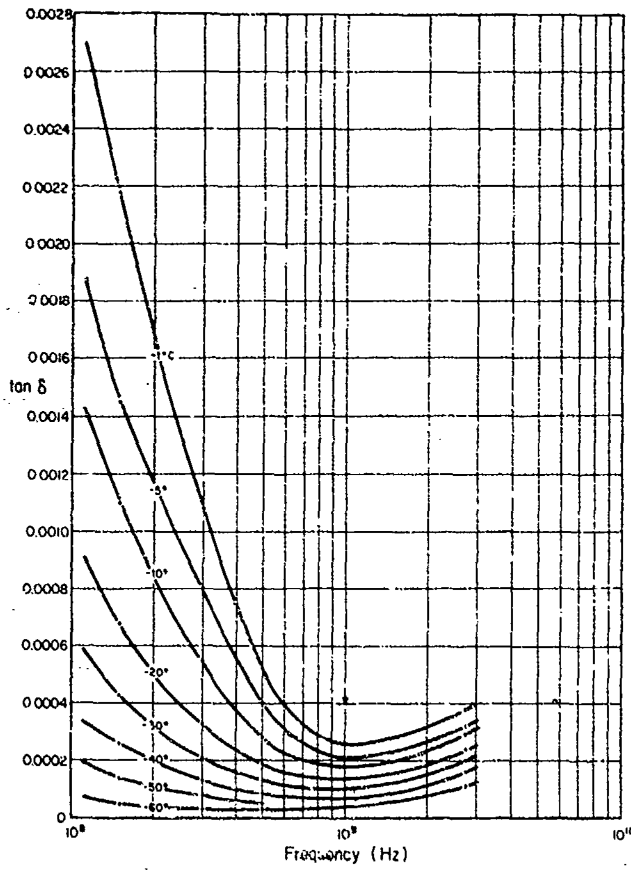
Sample, Source	Temp. (^{o}/C)	110*	150	300	500	1000	2700
Dartmouth No. 12	-1	.0030	.0022	.00108	.00052	.0004	.00038
	5	.0019	.00144	.00076	.00040		.00034
	10	.00145	.00110	.00055	.00028		.00030
	20	.00092	.00068	.00033	.00019		.00024
	30	.00059	.00043	.00021	.00013		.00020
	40	.00034	.00026	.00013	.00008		.00016
	50	.00020	.00014	.00008	.00005		.00014
	60	.00008	.00005	.00003	.00003		.00013
Dartmouth No. 14	-1	.039	.037	.0225	.0200	.0122	
	5	.026	.025	.0200	.0130	.0080	
	10	.0195	.0190	.0145	.0097	.0067	
	15	.017	.0157	.0107	.0082	.0054	
	20	.015	.0130	.0091	.0068	.0045	.0044
	25	.013	.0106	.0067	.0047	.0030	.0029
	30	.010	.0080	.0048	.0033	.00205	.00185
	40	.0058	.0045	.0026	.0017	.00112	.00065
	50	.0028	.0023	.0015	.00098	.00062	.00030
	60	.0014	.0012	.00078	.00054	.00035	.00016
Tuto Tunnel	See data for Dartmouth No. 12 (no measurable difference)						
Little America	-1	.0049	.0037	.0018	.00106	.00054	.00038
	5	.0035	.0026	.0013	.00072	.00037	.00032
	10	.00286	.00217	.00108	.00056	.00025	.00027
	20	.0020	.00154	.00078	.00038	.00018	.00024
	30	.00146	.00116	.00057	.00029	.00014	.00020
	40	.00105	.00085	.00044	.00025	.00013	.00014
	50	.00076	.00057	.00030	.00021	.00012	-

* 110 MHz values are extrapolated, not measured.

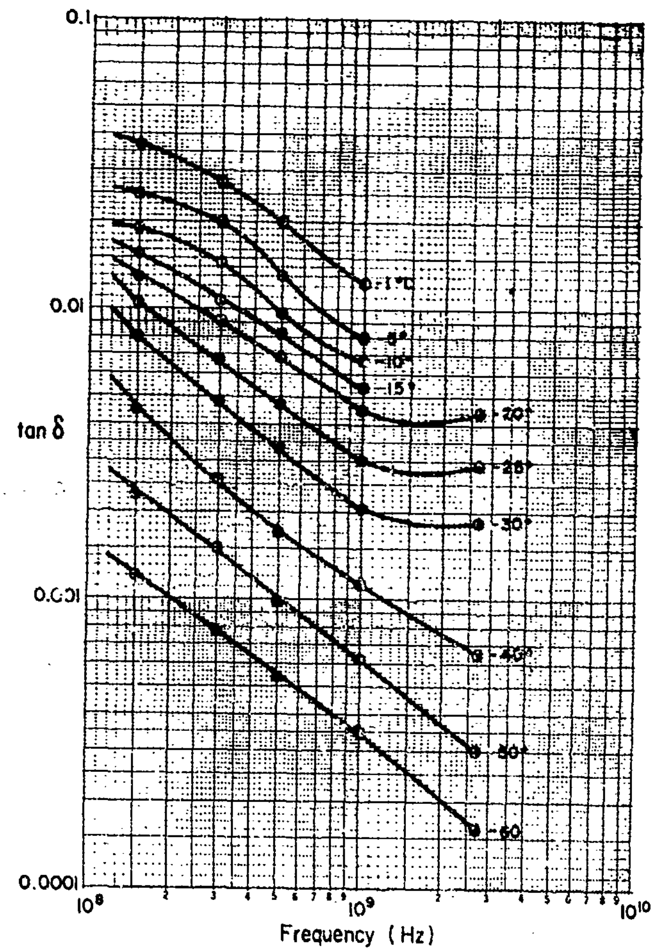
Sample, Source	Temp. (^{o}/C)	110	150	300	500	1000	2700
Arctic	-1			-			.00033
	5			-			.00029
	10		Cooling failed, sample melted				.00024
	20			-			.00018
	30			.00045			.00016
	40			.00032			.00014
	50			.00022			.00013
	60			.00015			.00013

Ices (cont.)

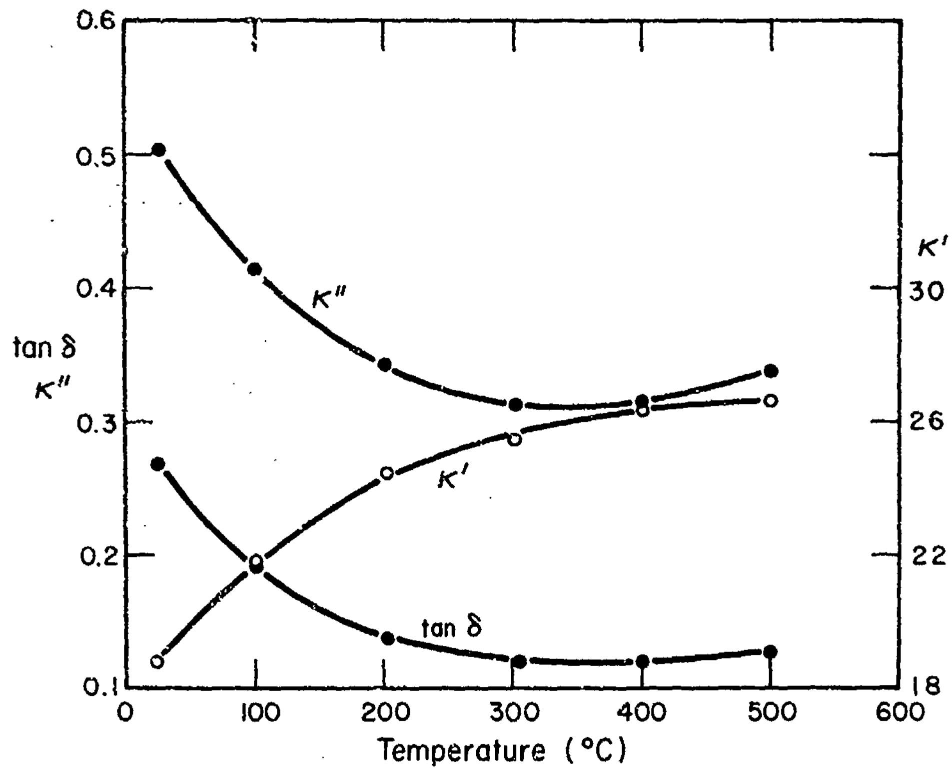
Dartmouth No. 12



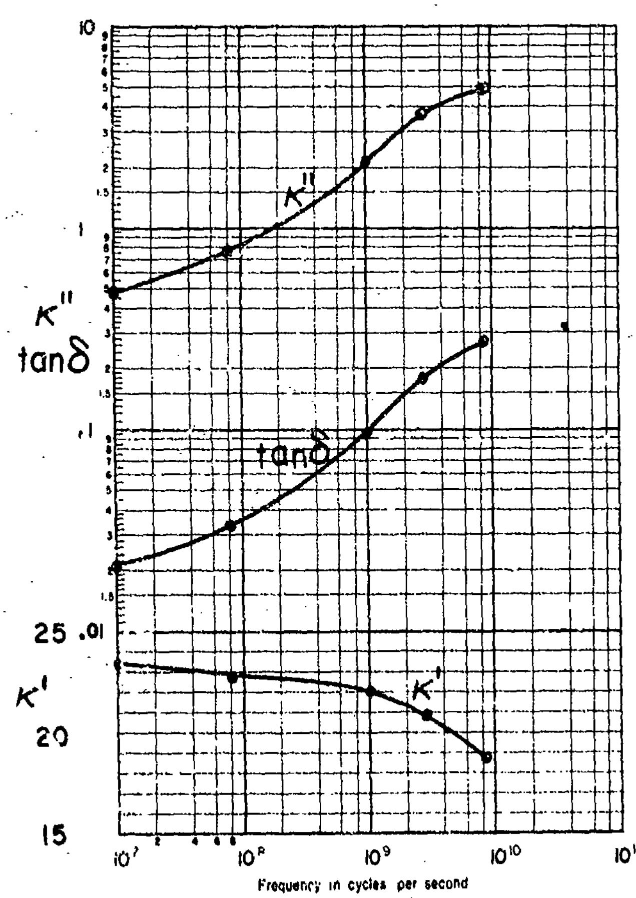
Sea ice



CFI 1003



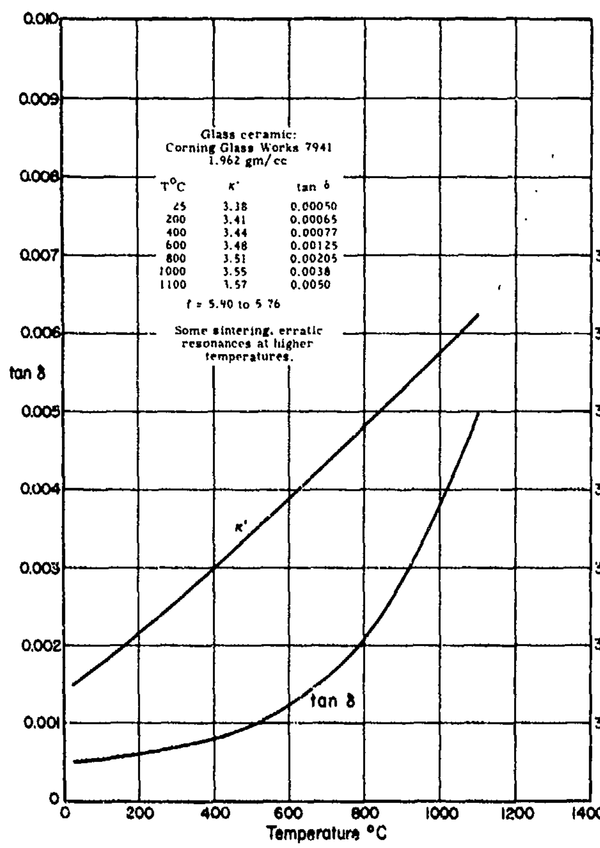
CFI 1006

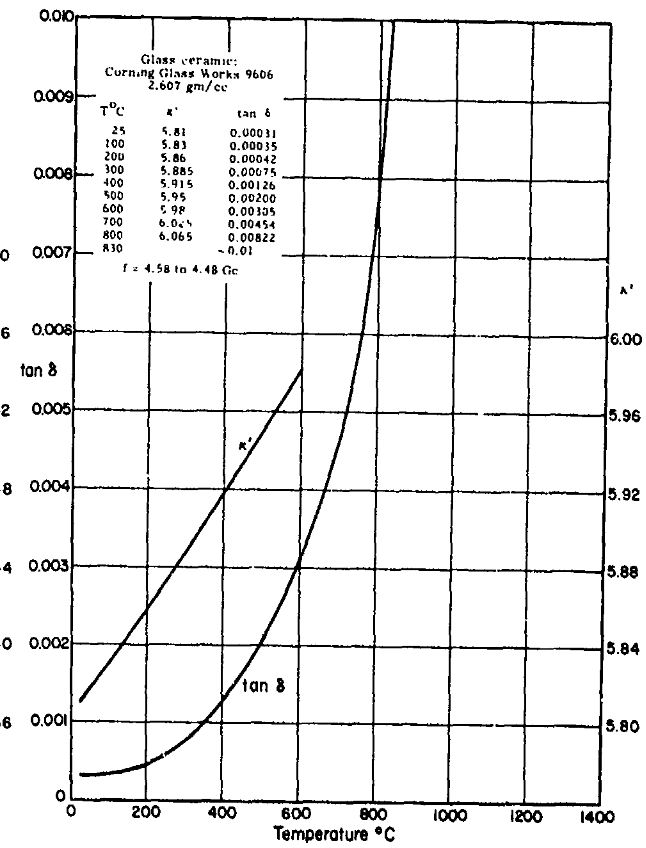


Miscellaneous Inorganics (cont.)

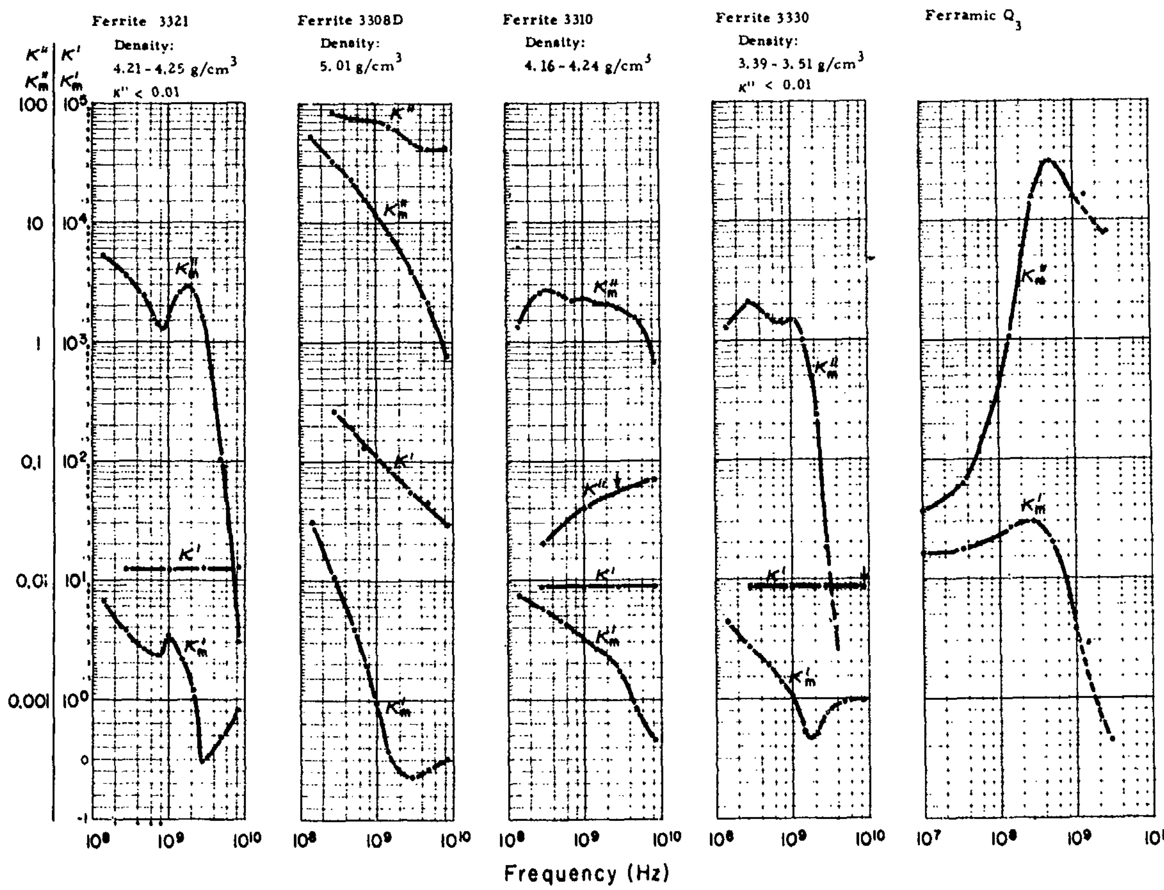
Corning Code 0330 | Corning Glass

3 GHz	$25^{\circ}C$
κ	tan δ
6.58	.0055

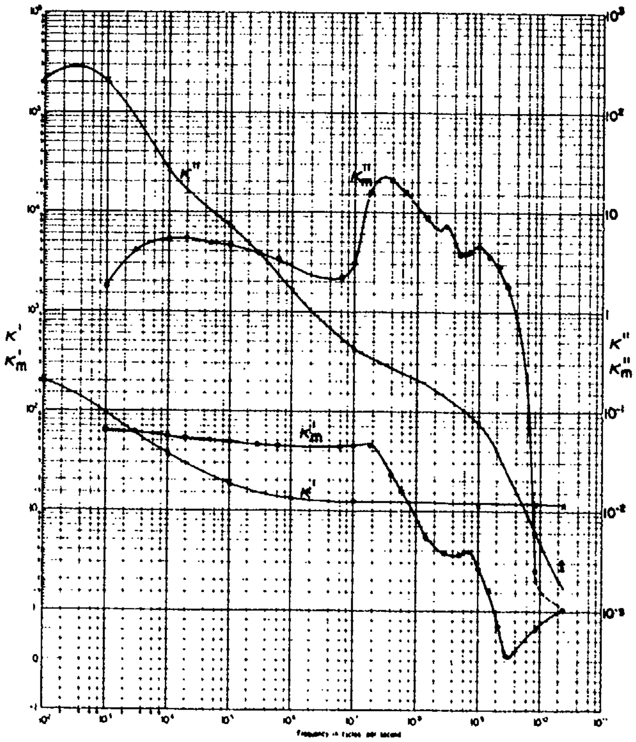




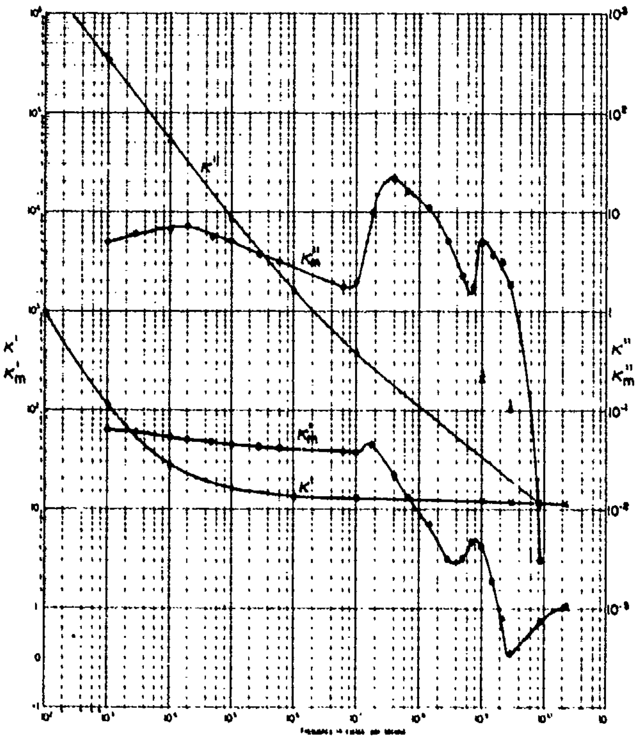
Ferrites


Ferrite 3321
Density:
4.21 - 4.25 g/cm3
κ'' < 0.01
Ferrite 3308D
Density:
5.01 g/cm3
Ferrite 3310
Density:
4.16 - 4.24 g/cm3
Ferrite 3330
Density:
3.39 - 3.51 g/cm3
κ'' < 0.01
Ferramic Q3
κ''
κ'
κ''m
κ'm
100
10
1
0.1
0.01
0.001
10^5
10^4
10^3
10^2
10^1
10^0
0
-1
10^7
10^8
10^9
10^10
Frequency (Hz)

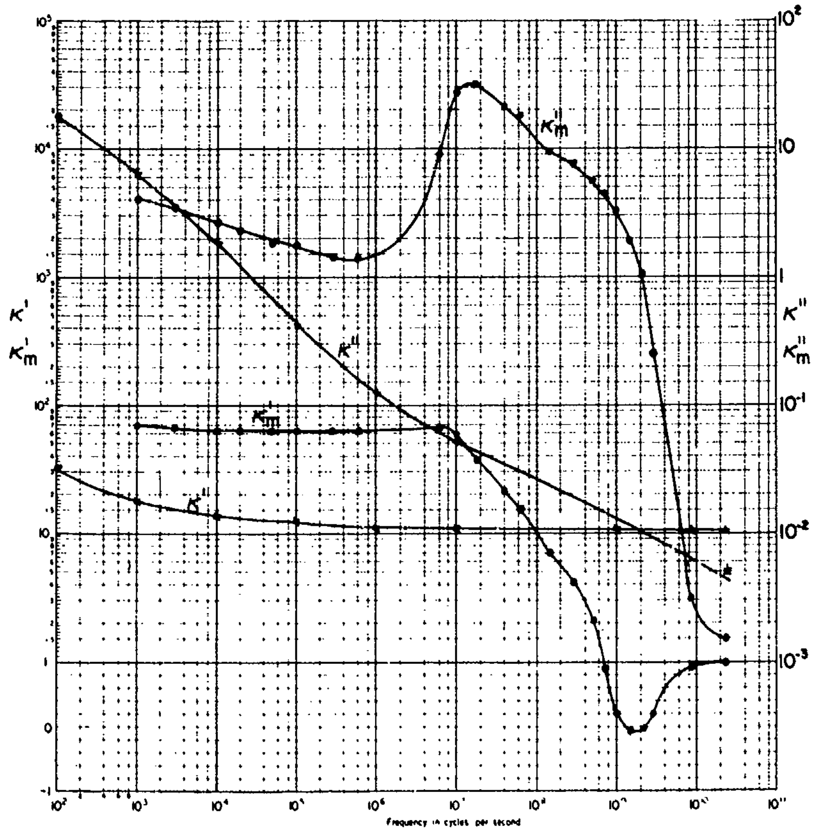
R-1



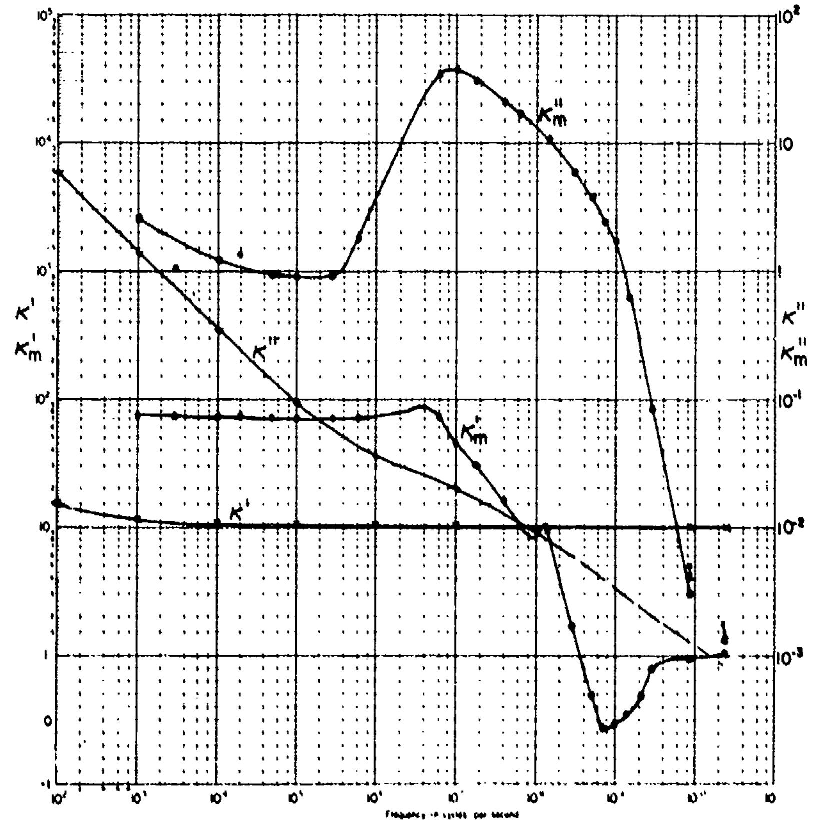
R-4



R-5


10⁵
10⁴
10³
10²
10
1
0
-1
10²
10
1
10⁻¹
10⁻²
10⁻³
κ'
κ'm
κ''
κ''m
κ''m
κ''
κ'm
κ''
10²
10³
10⁴
10⁵
10⁶
10⁷
10⁸
10⁹
10¹⁰
10¹¹
Frequency in cycles per second

R-6


10⁵
10⁴
10³
10²
10
1
0
-1
10²
10
1
10⁻¹
10⁻²
10⁻³
κ'
κ'm
κ''
κ''m
κ''m
κ''
κ'm
κ'
Frequency in cycles per second

Havelex, glass-bonded mica
At 8.52 GHz, 25°C

Haveg Industries, Inc.
Taunton Division

Type	κ'	tan δ
1080	6.35	.0025
1090	6.17	.0058
1101	8.89	.0027
2101	6.35	.0013
2103	9.2	.0021
2801	6.35	.0020
2803	6.05 - 6.39	.00255 - .0026

Isomica 4950

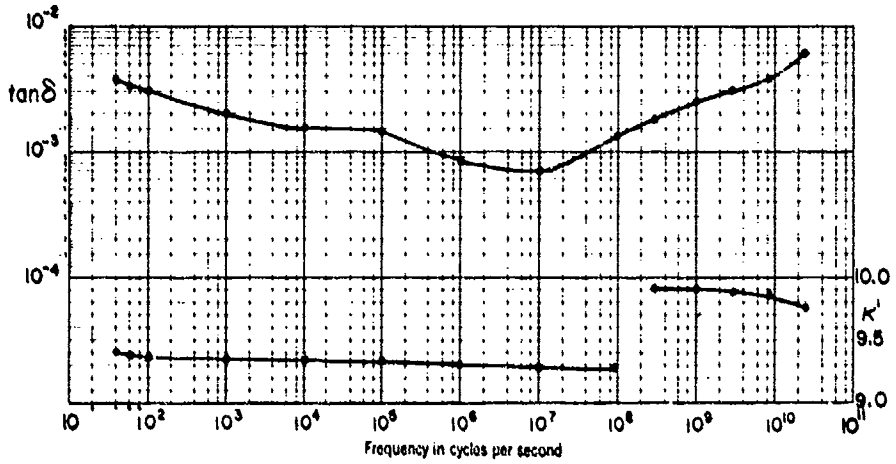
General Electric
Electronic Components Div.

Vacuum baked for 36 hrs. at 125°C, E ∥ sheet

Freq. (MHz)	κ	tan δ
300	5.33	.0013
8520	5.31	.00207
8520	5.32*	.0025*

* 50% relative humidity.

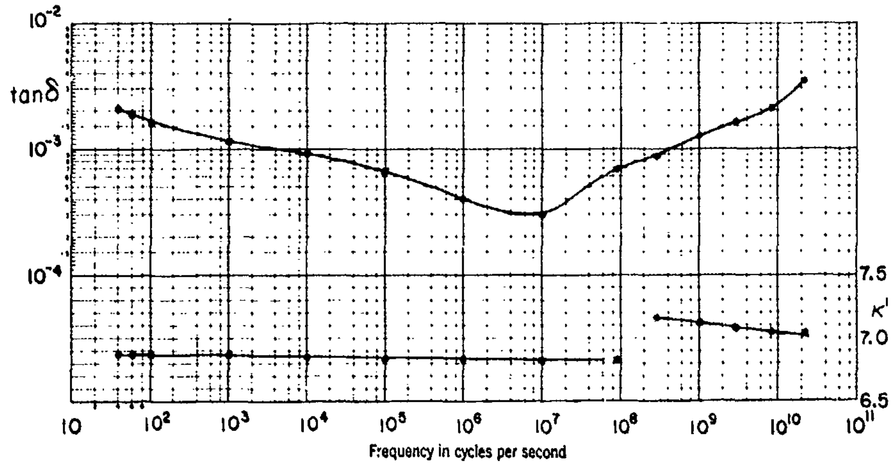
Mycalex 410



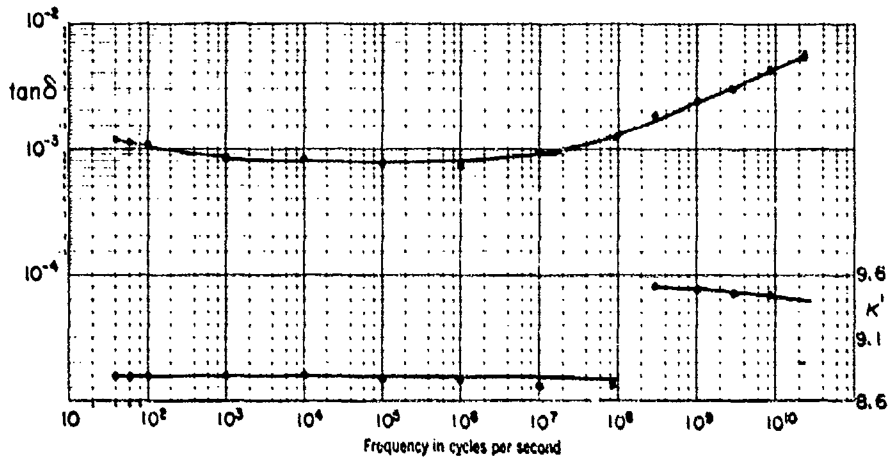
Note: all Mycalex samples from sheet stock. 10^2 through 10^8 Hz, E ⊥ sheet. 3×10^8 to 2.4×10^{10} Hz, E ∥ sheet.

Mycalex (cont.)

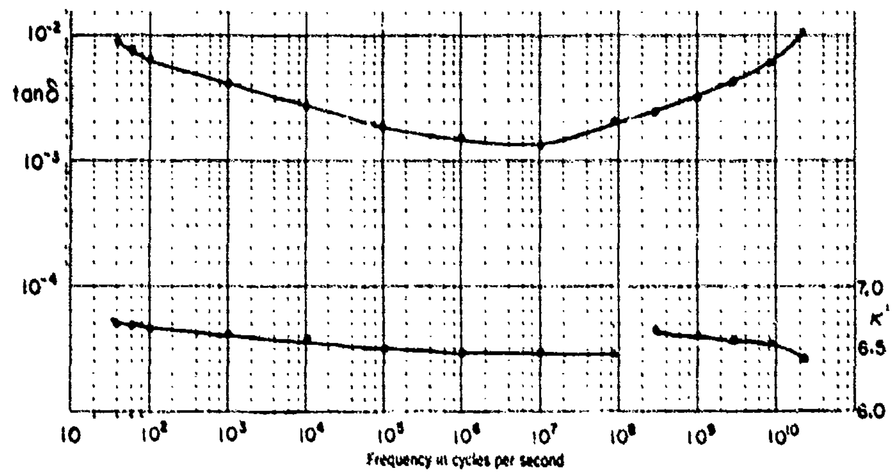
500



555

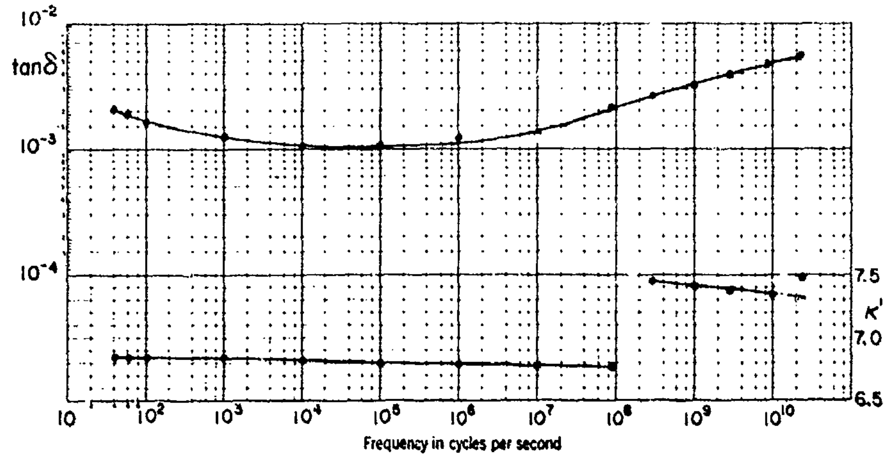


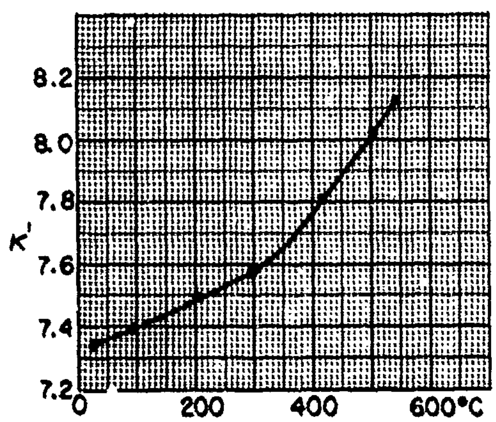
560

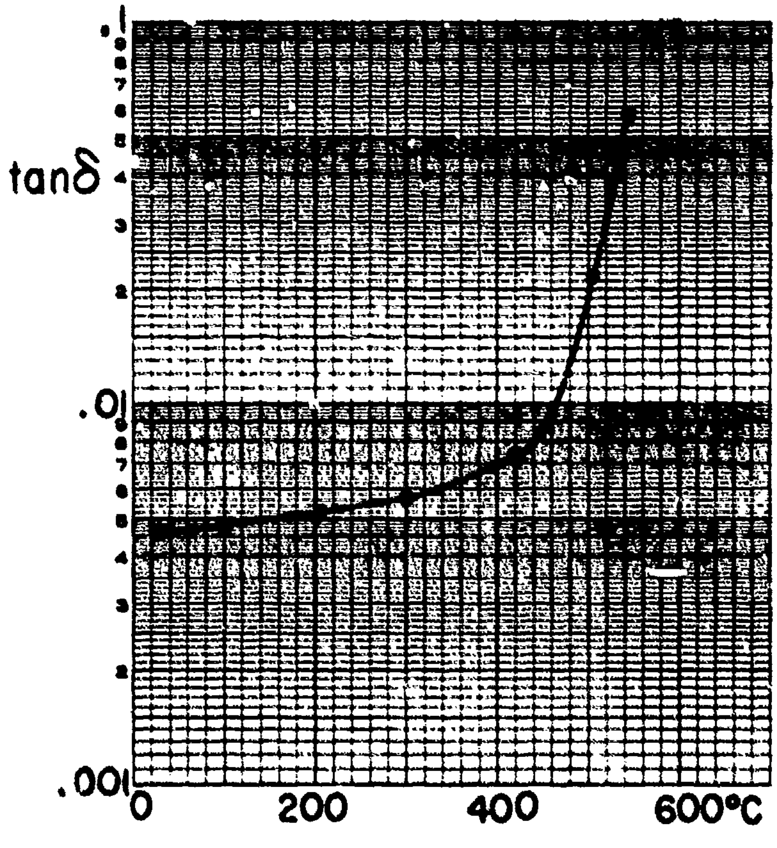


Mycalex (cont.)

620







California Highway Department

Asphalt pavement

Sample	Density	(Hz)	10^5	10^6	10^7	10^8
S	Dry	κ	4.51	4.34	4.21	4.14
		tan δ	.0280	.0221	.0181	.0198
S	Wet	κ	42.0	17.7	9.03	6.54
		tan δ	.875	.638	.444	.233
L	Dry	κ	4.79	4.73	4.70	4.61
		tan δ	.0187	.0158	.0123	.0121
L	Wet	κ	14.48	9.28	6.65	6.01
		tan δ	.368	.280	.190	.104

Raytheon

Asphalt pavement at 40% R.H., 25°C, 14 GHz

Sample No.	Thickness (cm)	Density (g/cm^3)	H_2O (%)	Orientation	κ'	tan δ
1	0.1			Independent	4.73	.0114
2	0.1			"	4.62	.0103
3	0.1				5.03	.0120
4	0.1				5.48	.0095
5	0.91	2.35	.754	Face 1	6.02	.021
				Face 1, 90°	5.53	.052
				Face 2	5.37	.204
				Face 2, 90°	5.44	.102

Liquid asphalt

Esso

f (Hz)	κ'	tan δ
1×10^9	2.46	.0017
3×10^9	2.46	.0019
8.5×10^9	2.46	.0013

Solid asphalt formed by burning liquid for 2 days at 300°C

1.5×10^6	2.64	.0043
10^7	2.64	.0030
1.8×10^7	2.64	.0027
4×10^7	2.64	.0025
8.5×10^9	2.63	.0018

Miscellaneous Inorganics

Concrete pavement — California Highway Department

Sample	Density	(MHz)	0.1	1	10	100
S1	Dry	κ	9.05	7.97	7.01	6.57
		tan δ	.0946	.0913	.0730	.0536
S1	Wet	κ	176.5	69.2	23.5	13.2
		tan δ	.822	1.088	.734	.485

Concrete pavement at 40% R. H., 25°C, 14 GHz — Raytheon

1	0.1			Various	5.03-5.06	.026-.029
2	0.1			Various	5.06-5.17	.034-.030
3	0.335	2.14	2.21	Face 1	5.21	.059
				Face 1, 90°	5.20	.0612
				Face 2	5.30	.0509
				Face 2, 90°	5.26	.0505
4	0.453	2.04	2.81	Face 1	4.71	.0470
				Face 1, 90°	4.60	.0455
				Face 2	4.70	.0487
				Face 2, 90°	4.55	.0487

Miscellaneous Inorganics

Salt Raytheon

Sample	Condition		10^8	$3x10^8$	10^9
Granulated	As received	κ	3.28	3.27	3.25
purified salt	d = 1.39	tan δ	0.0019	0.0018	0.0040
		% H_2O	0.05	0.06	.08
	Dry	κ	3.25	3.25	3.23
	d = 1.39	tan δ	0.0009	.0006	0.0012
Fine flake	As received	κ	2.72	2.67	2.63
salt	d = 0.960	tan δ	0.026	0.037	0.025
		% H_2O	0.28	0.36	0.40
	Dry	k	2.64	2.63	2.62
	d = 0.956	tan δ	0.0017	0.0014	0.0031

John Manville Service Boards at 25°C The Sippican Corporation

	Style 61 - 1/4"		Style 71 - 1/8"	
MHz	κ	tan δ	κ	tan δ
0.05	12.78	0.429	5.18	0.342
1	6.43	0.347	3.46	0.150
60	3.87	0.091	3.07	0.017
300*	4.20	0.188	3.54	0.043
1000*	3.98	0.137	3.50	0.024
0.05*	149.	0.733	63.8	0.625
1*	46.3	0.740	15.8	1.09

* Electric field in plane of sheet, others E sheet.

III. ORGANIC COMPOUNDS

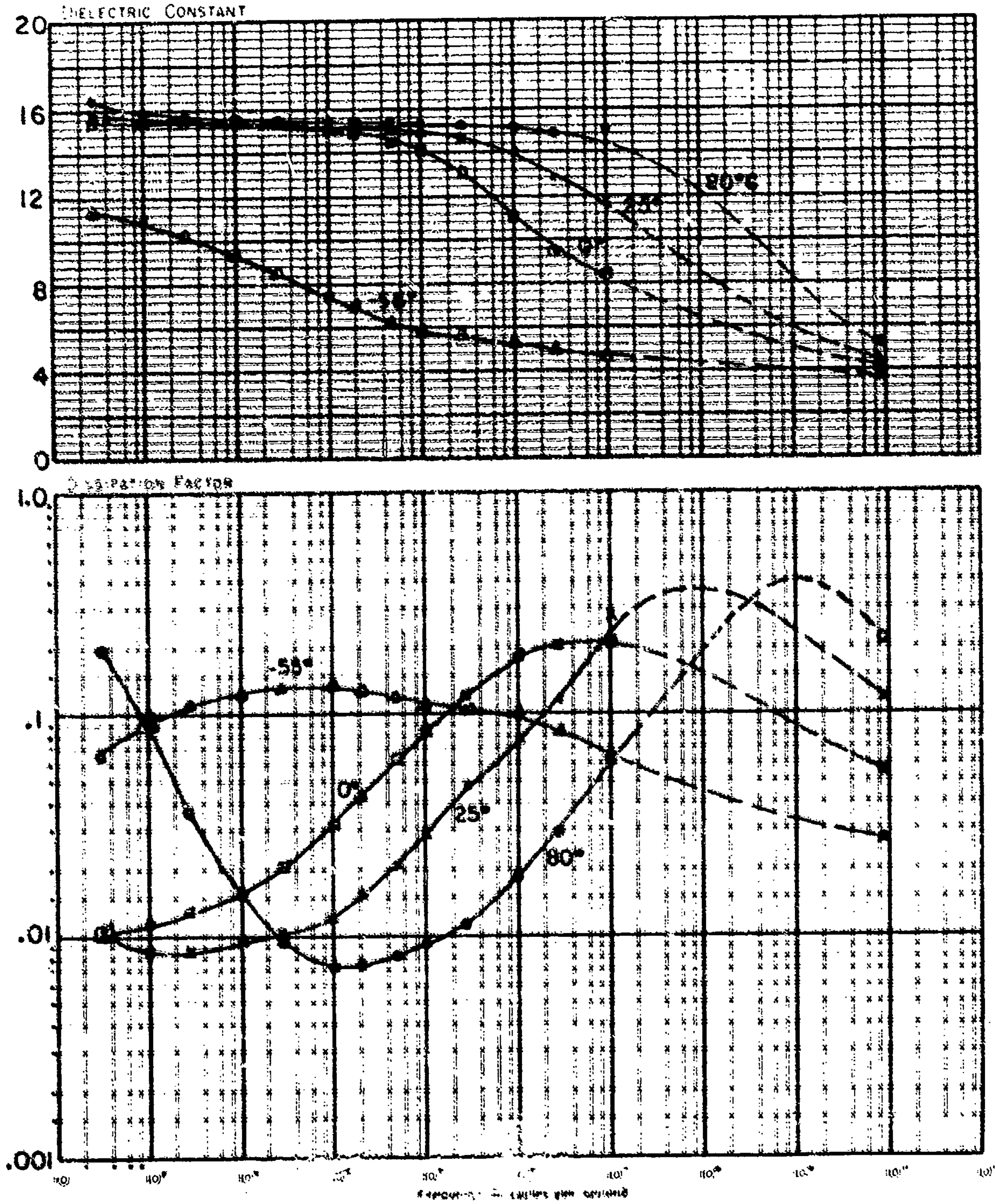
(Listed according to manufacturer or source)

Artificial concrete — American Concrete Products

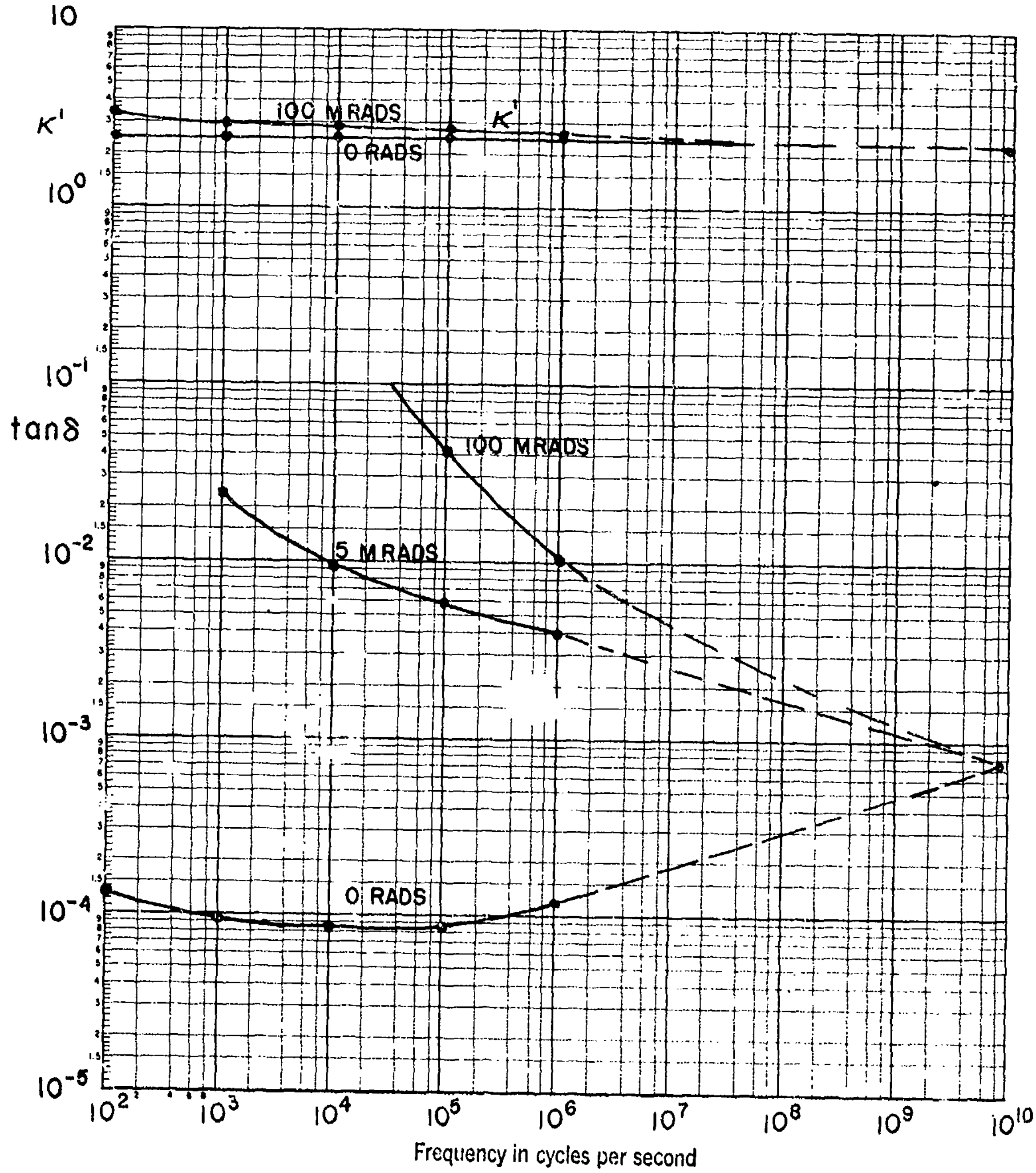
Material measured to be isotropic in κ within 0.5%

Freq. (MHz)	150	300	1000	3000
κ	6.06	6.04	6.02	6.0
tan δ	0.0107	0.0134	0.0125	0.0123

Cyanoethylated cotton moulding — American Cyanamid



Cymac 325, American Cyanamid
including effect of van De Graaff irradiation



Conformal coating 1517-36-3 Amicon Corporation
25^oC, 50% relative humidity

Freq. (Hz)	κ	tan δ
10^2	4.31	0.0206
10^3	4.21	0.0204
10^6	3.76	0.0298

Volume resistivity 3.7×10^{13} ohm-cm

Surface resistivity $>6 \times 10^{14}$ ohms per square

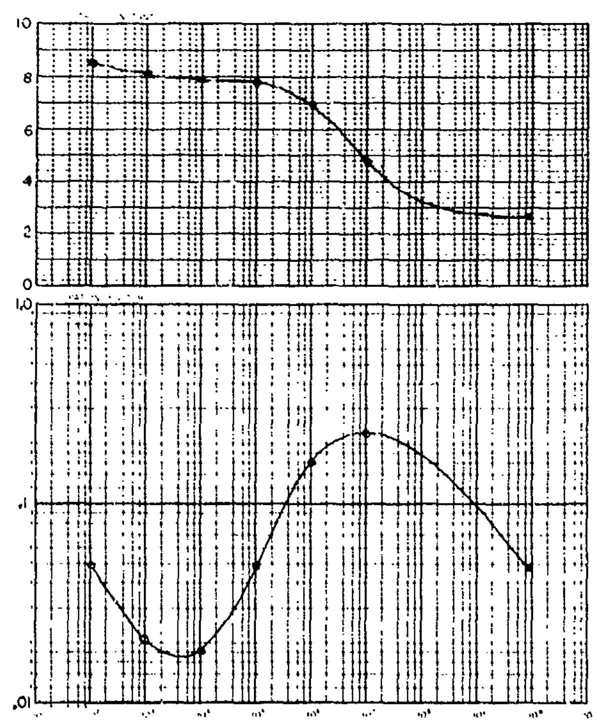
Polyethylene, irradiated
At 25°C

Source: Amphenol Corp.

Freq. (Hz)	κ'	tan δ
10^3	$2.28 \pm .02$	$.59 \pm .05$
10^6		$.82 \pm .05$
10^8		$2.3 \pm .3$
4×10^8	$2.27 \pm^{.02}_{.01}$	$2.9 \pm .5$
10^9		$2.8 \pm .3$
3×10^9		$2.6 \pm .3$
8.5×10^9	$2.260^{+.01}_{-.005}$	$2.5 \pm .2$

Polyvinylidene fluoride

AVCO Research



Polypropylene

Avisun Corporation
Post Road
Markus Hook, Pa. 19061

Freq., Hz	$T^{o}C$	Natural κ	Natural $10^4 \tan \delta$	Plateable 12-270A κ	Plateable 12-270A $10^4 \tan \delta$
10^2	25	2.26	1.50	2.41	15.2
$2x10^2$			1.30		
$4x10^2$			1.18		
10^3			1.36	2.41	11.8
$3x10^3$			1.50		
10^2			1.65	2.39	10.5
$2x10^4$			1.68		
$5x10^4$			1.66		
10^5		2.25	1.51	2.38	8.70
10^6		2.25	0.96	2.37	7.25
10^7		2.25	1.26	2.36	6.55
10^8		2.25	2.04	2.36	8.2
$3x10^8$		2.25	2.8	2.35	12.4
10^9		2.25	4.7	2.35	17.5
$3x10^9$		2.25	4.0	2.35	15.7
$5x10^9$	25	2.245	3.7	2.344	12.1
	-55	2.265	3.0	2.352	6.0
	-75	2.271	2.7		
	-195	2.308	0.7 ± 0.3	2.375	2.8
$8.5x10^9$	25	2.245	3.6	2.343	12.3

Polypropylene (cont.) Avisun Corporation

Natural, at 8.52 GHz

Sample	Density (g/cm^3)	T°C	κ	tan δ
1 stacked sheet pcs		25	2.246	.00033
2 stacked injection molded pcs		25	2.236	.00035
3 rod	.9073	25	2.245	.00037

Polypropylene, plateable Avisun Corporation

12-270A, at 8.52 GHz

Sample	Density	T°C	κ	tan δ
4 stacked injection molded pcs	.9500	25	2.442	.00145
5 rod	.9303	25	2.343	.00123

Polytetrafluoroethylene, fiberglas laminate

The Budd Company
Polychemicals Division

DiClad-522,
E ⊥ sheet

All values of tan δ multiplied by 10^4

T°C	Freq. (Hz)	10	10^2	10^3	10^4	10^5	10^6	10^7	$5.5x10^7$	$9x10^7$	$3.14x10^9$*
25	κ	2.739	2.740	2.738	2.737	2.735	2.734	2.733	2.732	2.731	2.712
	1 tan δ	8.6	7.0	6.7	6.1	6.3	6.95	7.7	10.0	11.7	22.5
100	κ		2.710	2.705	2.704	2.698	2.696	2.683			2.680
	1 tan δ		11.1	8.10	8.25	7.17	7.07	7.7			31
250	κ		2.554	2.534	2.522	2.503	2.502	2.49			
	1 tan δ		79.0	36.3	20.35	14.9	11.6	10.6			
-78	κ		2.796	2.793	2.790	2.784	2.78	2.78			2.752
	1 tan δ		4.2	5.9	6.8	7.1	7.7	9.8			17
-195	κ	2.801	2.799	2.794	2.792	2.787					2.758
	1 tan δ	.0005	2.2	4.5	5.1	5.4					12
-269	κ	2.789	2.789	2.784	2.783	2.780					
	1 tan δ	.0003	1.2	2.0	2.2	2.1					

* Copper cavity

E ‖ sheet

T°C	Freq. (Hz)	$3x10^8$	10^9	$3x10^9$	$8.5x10^9$	$1.4x10^{10}$	$2.4x10^{10}$
25	κ	3.155	3.153	3.152	3.146	3.133	3.127
	tan δ	28	30	33	40	48	52
100	κ				3.11		
	tan δ				39		
250	κ				3.03		
	tan δ				36		
-54	κ				3.17	3.13	
	tan δ				35	39	
-195	κ				3.22	3.12	
	tan δ				28	31	

Copper-clad laminate PE1153 The Budd Co., Polychem Division

E ⊥			10^2	10^3	10^4	10^5	10^6	10^7
3-terminal, liquid immersion, unclad *	25	κ			2.420			
		tan δ						
Declad †	25	κ			2.451			
		tan δ						
3-terminal, clad	26	κ	2.650	2.465	2.438	2.432		
		tan δ	.0945	.0279	.00484	.00093		
	-195	κ	2.416	2.415	2.414	2.411		
		tan δ	.00030	.00033	.00036	.00022		
	-54	κ	2.433	2.421	2.417	2.413		
		tan δ	.00042	.00050	.00052	.00031		
2-terminal, clad, meas. 12-21-70	25	κ	2.495	2.475	2.471	2.469	2.468	2.468
		tan δ	.01816	.00307	.00083	.00050	.00055	.00035
3-terminal, clad, 2nd sample	25	κ	2.843	2.504	2.457	2.449		
		tan δ	.141	.0491	.00811	.00126		
	96	κ	2.486	2.398	2.389	2.384		
		tan δ	.0708	.01343	.00230	.00050		
	250	κ	2.257	2.240	2.232	2.222		
		tan δ	.0263	.00568	.00238	.00111		
	25	κ	2.759	2.510	2.459	2.451		
		tan δ	.0970	.0390	.00748	.00115		
2-terminal, clad	-54	κ	2.484	2.484	2.484	2.479	2.464	2.456
		tan δ	.00034	.00044	.00065	.00062	.00059	.00110
	-195	κ	2.490	2.487	2.485	2.484	2.482	2.470
		tan δ	.00029	.00038	.00053	.00028	.00049	.00091
	25	κ				2.462	-	2.458
		tan δ				.00050	-	.00033
	96	κ	2.474	2.464	2.461	2.460	2.458	2.455
		tan δ	.01193	.00226	.00084	.00059	.00058	.00068
	250	κ	2.333	2.319	2.312	2.309	2.298	2.295
		tan δ	.01013	.00340	.00177	.00147	.00097	.00070
	25	κ	2.422	2.415				
		tan δ	.00995	.00189				
E ∥								
2-terminal, unclad	25	κ	2.434	2.533	2.431	2.428	2.416	2.413
		tan δ	.0037	.00094	.00061	.00035	.00052	.0005

* Refers to sheet stock received without copper.

† Refers to a sample made by mechanically stripping the copper-clad sheet.

Resonant-Cavity Measurements:

$\sim$ 8.5 GHz, sample constrained in parallel direction, allowed to expand with temperature against a force 30 lb/sq in the perpendicular direction. Unclad stock.

	E ⊥		E ∥		
$T^{o}C$	κ	tan δ	κ	tan δ	Thickness cm
-194	2.466	.00063	2.420	.00095	1.911
-54	2.437	.00070	2.397	.00104	1.917
23	2.421	.00091	2.383	.00130	1.924
96	2.396	.00117	2.367	.00147	1.948
250	2.296	.0022	2.246	.00185	2.093

Standing-wave method, 25°C

E ∥ , one piece unclad	2.387	.00128

EKONOL (polyester resin) The Carborundum Company

Sample 1

Frequency, Hz	T°C	κ	tan δ
10^2	25	3.216	.00289
10^3		3.210	.00316
10^4		3.185	.00336
10^5		3.168	.00348
10^6		3.156	.00325
10^7		3.148	.00220
10^8		3.140	.00215
$8.5x10^9$		3.120	.00281
	99	3.11	.0030
	155	3.08	.0040
	207	3.07	.0061
	284	3.04	.0104
	350	3.03	.0230
	420	3.03	.0230
	217	2.99	.0067
	25	2.96	.0025

Sample 2

T°C	Freq., Hz	10^2	10^3	10^4	10^5	10^6	10^7
25	κ	2.958	2.954	2.942	2.939	2.923	2.891
	tan	0.00136	0.00201	0.00251	0.00325	0.00337	0.0021
100		2.982	2.962	2.955	2.945	2.926	2.898
	tan	0.00367	0.00263	0.00262	0.00303	0.00391	0.0040
180	κ	3.252	3.182	3.130	3.077	3.031	2.993
	tan	0.0444	0.0160	0.0120	0.0108	0.0099	0.0096
250	κ	4.606	3.415	3.244	3.177	3.096	3.050
	tan	0.767	0.188	0.0368	0.0151	0.0131	0.0138
325	κ	23.57	5.646	3.574	3.267	3.190	3.140
	tan	1.52	1.194	0.316	0.0567	0.0161	0.0127

Polytetrafluoroethylene film

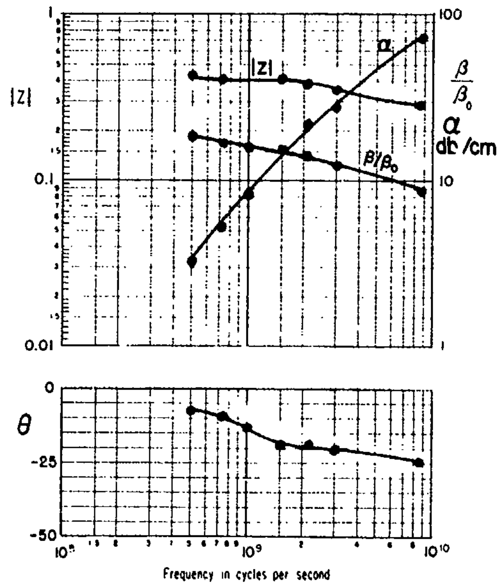
Zitex

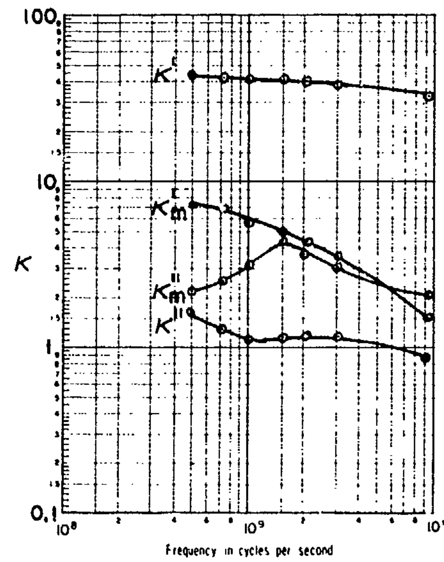
Density 0.463 g/cm^3

25°C, 8.52 GHz: κ = 1.194, tan δ = .00010

Chemplast Inc.
150 Dey Road
Wayne, N.J. 07470

Polyiron (Carbonyl) H. I. Crowley





Custom Materials — Custom Materials Inc.

Custom load 4101

Freq. (GHz)	T^oC	κ	$\tan \delta_e$	μ'/μ_o	$\tan \delta_m$
3	25	13.8	.050	2.69	.451
8.5	25	13.3	.031	1.65	.747
8.5	-67	13.7	.006	1.57	.748
8.5	85	14.5	.051	1.68	.735

Custom 707-4

25^oC, 8.52 GHz: $\kappa = 4.04$, $\tan \delta = .00090$

Custom 707-(3.75)

25^oC, ö.52 GHz: $\kappa = 3.753$, $\tan \delta = .00076$

FLUORGLAS E 650/2-1200 — Dodge Industries, Inc.

TFE-fiberglas laminate

		E ⊥		E ∥	
Freq., GHz	T^oC	κ	$\tan \delta$	κ	$\tan \delta$
8.5	23	2.505	.0014	2.847	.0036
4	-195	2.533	.00082	2.896	.00172

Moulding compound 306 — Dow Corning

T°C	1 GHz κ'	1 GHz tan δ	3 GHz κ'	3 GHz tan δ
25	3.92	.00538	3.87	.00622
76	3.91	.0052	3.86	.0058
103	3.90	.0052	3.85	.0058
129	3.89	.0051	3.84	.0056
150	3.87	.0050	3.83	.0055
216	3.83	.0050	3.78	.0051
255	3.80	.0052	3.75	.0051
305	3.77	.0056	3.72	.0054
410	3.68	.0064	3.63	.0068
504	3.62	.0058	3.58	.0066
301	3.75	.0048		

T°C	8.52 GHz κ'	8.52 GHz tan δ
-55	3.85	.0060
25	3.84	.0067
61	3.835	.00655
118	3.825	.0064
147	3.82	.00635
199	3.807	.00625
315	3.74	.00615
400	3.66	.0061
499	3.57	.0060
296	3.72	.0061

Silastic	T°C		1000 MHz	3000 MHz	8500 MHz
RTV 501	-55	κ'	3.17	3.07	
		tan δ	0.025	0.037	
	23	κ'	2.89	2.88	2.87
		tan δ	0.0053	0.0104	0.0175
	150	κ'	2.62	2.62	
		tan δ	0.042	0.0045	
RTV 521	23	κ'	3.33	3.32	3.31
		tan δ	0.0086	0.0153	0.025[illegible]
RTV 1602	-55	κ'	3.09	3.03	
		tan δ	0.0220	0.0308	
	23	κ'	2.93	2.92	2.91
		tan δ	0.0073	0.0117	0.0187
	150	κ'	2.77	2.75	
		tan δ	0.0044	0.0060	
RTV 5350	-55	κ'	3.22	3.14	
		tan δ	0.0234	0.0287	
	23	κ'	3.06	3.05	3.04
		tan δ	0.0043	0.0088	0.0166
	150	κ'	2.82	2.79	
		tan δ	0.0040	0.0043	
S-6538	-55	κ'	3.01	2.96	
		tan δ	0.0242	0.0260	
	23	κ'	2.99	2.98	2.97
		tan δ	0.0069	0.0124	0.0187
	150	κ'	2.78	2.77	
		tan δ	0.0039	0.0047	
Sylgard 182	-55	κ'	2.90	2.86	2.81
		tan δ	0.0200	0.024	0.029
	23	κ'	2.79	2.77	2.73
		tan δ	0.0081	0.0120	0.0199
	150	κ'	2.50	2.48	2.45
		tan δ	0.0026	0.0040	0.0073

Sylgard 182, at 1 MHz — Dow Corning

T°C	κ	tan δ
25	2.86	.00132
70	2.72	.00080
25 again	-	.00109
25 (after 24 hrs. in H_2O) wt. gain 0.019%	2.86	.00142

Sylgard 184, at 25°C

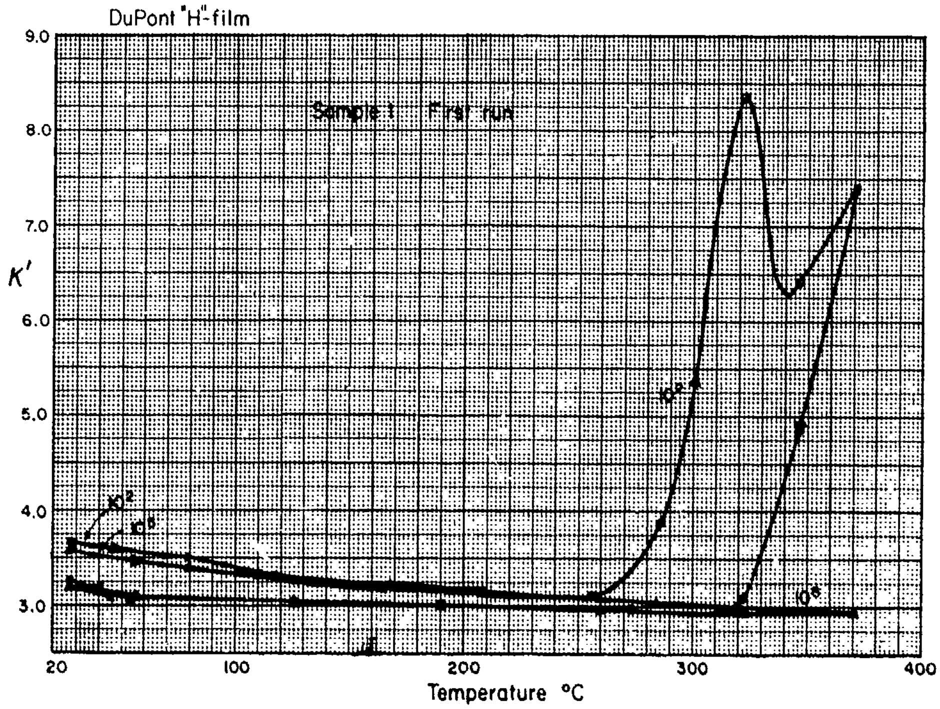
Freq. (Hz)	50	10^3	10^5	10^6
κ	2.86	2.86	2.84	2.84
10^4 tan δ	2	10.2	18.4	14.0

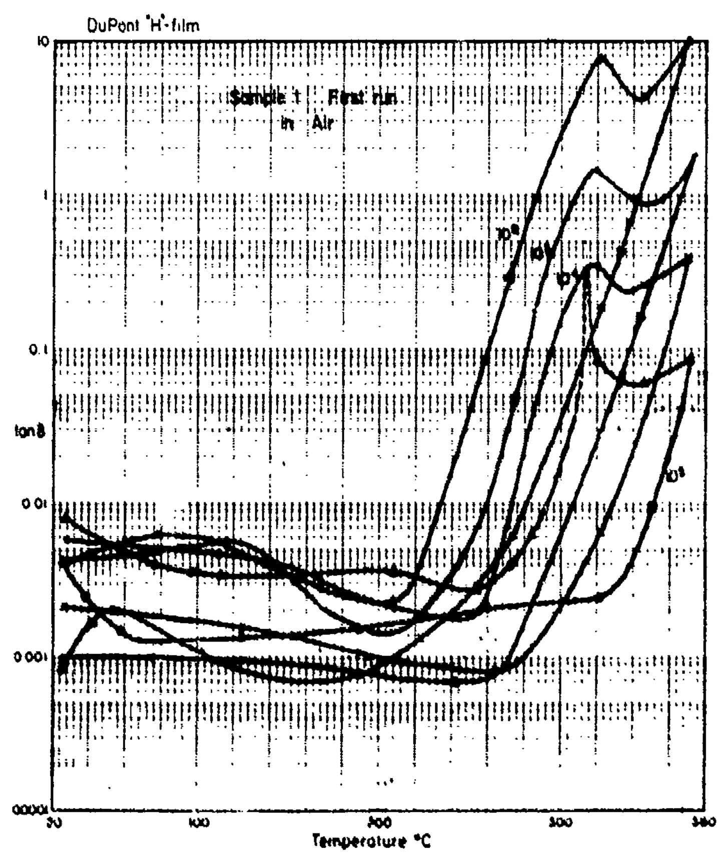
Sylgard 184 (2nd sample at 1 MHz)

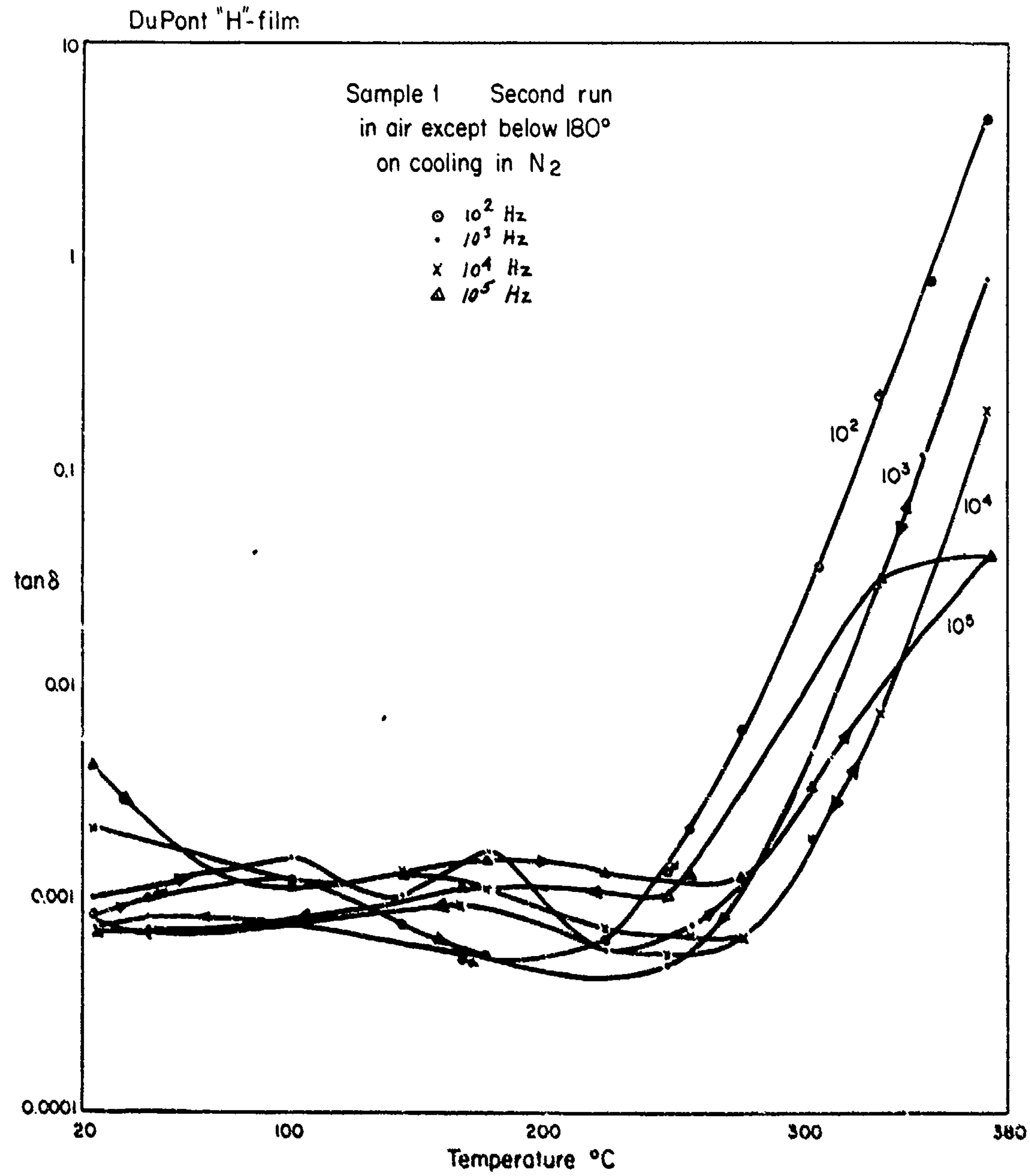
T°C	κ	tan δ
25	2.88	.00123
70	2.70	.00071
25	-	.00040
25 (after 24 hrs. in H_2O) wt. gain 0.025%)	2.89	.00129

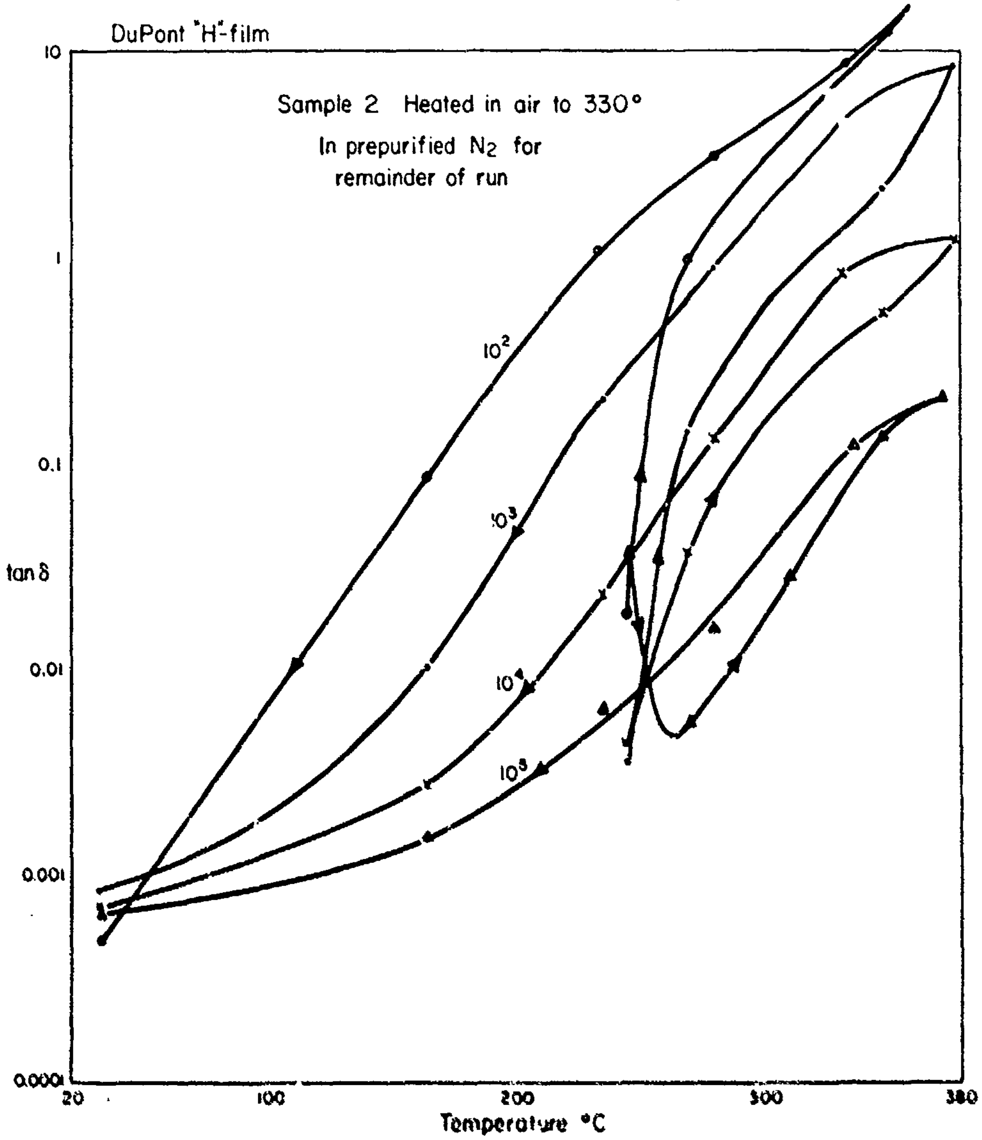
DC-92.007

8.52 GHz, 25°C, 50% R.H., κ' = 4.92; tan δ = 0.091


DuPont "H"-film
Sample 1 First run
K'
Temperature °C


DuPont "H"-film
Sample 1 First run
in Air
tan δ
Temperature °C


DuPont "H"-film
Sample 1 Second run
in air except below 180°
on cooling in N2
10² Hz
10³ Hz
10⁴ Hz
10⁵ Hz
10
1
0.1
tan δ
0.01
0.001
0.0001
20
100
200
300
380
Temperature °C
10²
10³
10⁴
10⁵



"Kapton" E. I. Dupont de Nemours and Co.

Type 500 H film, at 25°C, 45% relative humidity
Electric field in plane of sheet, $\kappa \pm 0.05$, $\tan\delta \pm 0.0005$

			After 48 hrs. at 100°C	
Freq. (GHz)	κ	tan δ	κ	tan δ
0.3	3.43	.0074	-	-
1	3.40	.0076	3.30	.0041
3	3.37	.0080	3.28	.0044
8.5	3.33	.0087	3.26	.0047
24	3.25	.0098	-	-

After 12 to 18 hrs. vacuum bake at 425°C, 2 microns, 8.52 GHz:

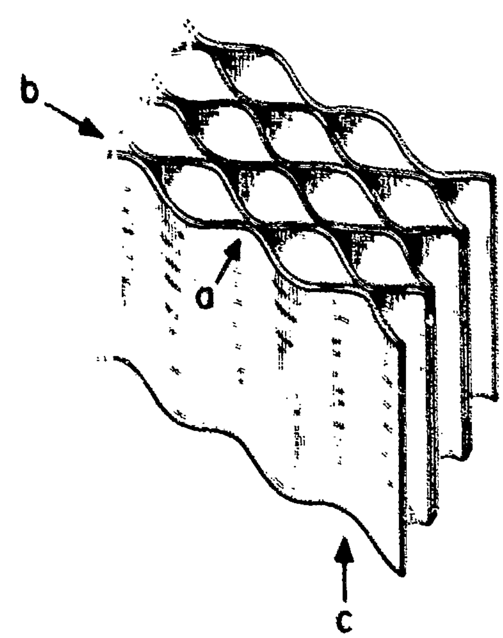
$\kappa = 3.03 \pm 0.1$, $\tan\delta = .0015 \pm .0003$

Nonex honeycombs At 8.52 GHz

E. I. du Pont de Nemours and Company

Sample No.	Density	a direction E ⊥ double-layer seam κ	tan δ	b direction E ∥ double-layer seam κ	tan δ	c direction E ∥ holes κ	tan δ
1	1.398	1.0348	.00089	1.0441	.00141	1.0855	.00212
2	2.892	1.0519	.00165	1.0669	.00229	1.0951	.00350
3	3.938	1.0788	.00176	1.1258	.00326	1.1444	.0041
4	4.039	1.0808	.00187	1.1020	.00278	1.1265	.0049
5	4.124	1.0827	.00274	1.1045	.00359	1.1351	.0046
6	4.259	1.0863	.00197	1.1340	.00382	1.1270	.0045
7	4.701	1.0928	.00315	1.1115	.00297	1.1455	.0047
8	5.603	1.0990	.00205	1.1781	.00468	1.1869	.0065
8*	5.603	1.1010	.00330	1.1667	.00628		

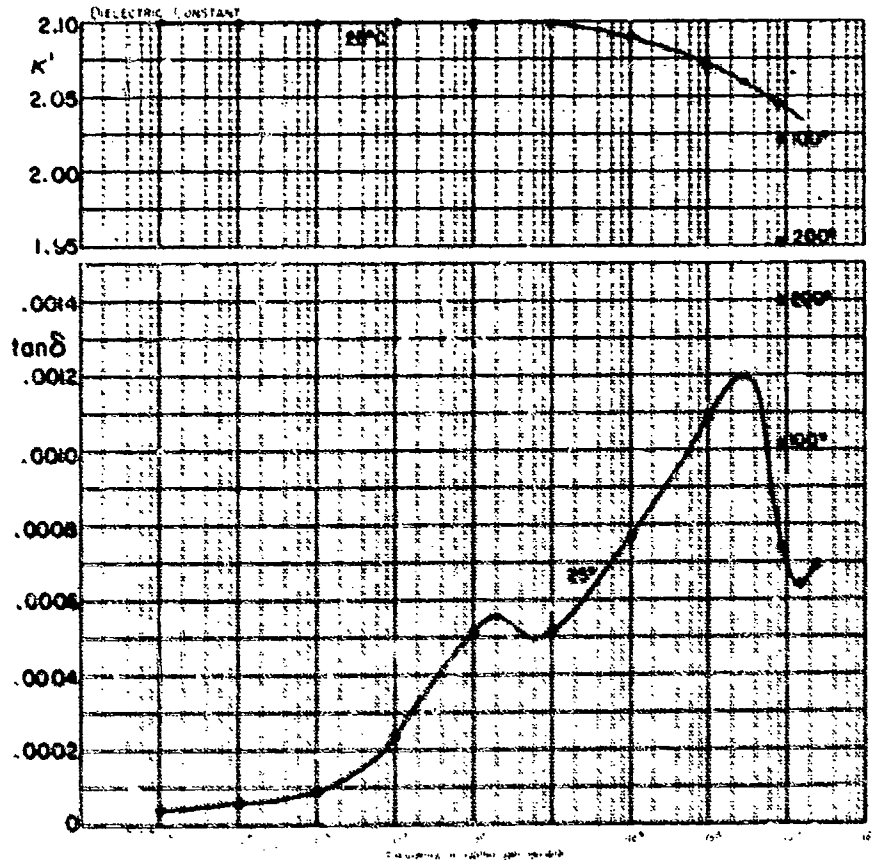
* At 100°C, all other values at 25°C

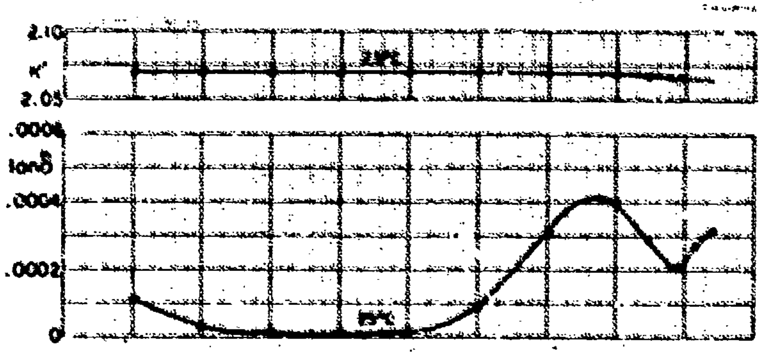


Teflon FEP (1963) E. I. Dupont de Nemours and Co.

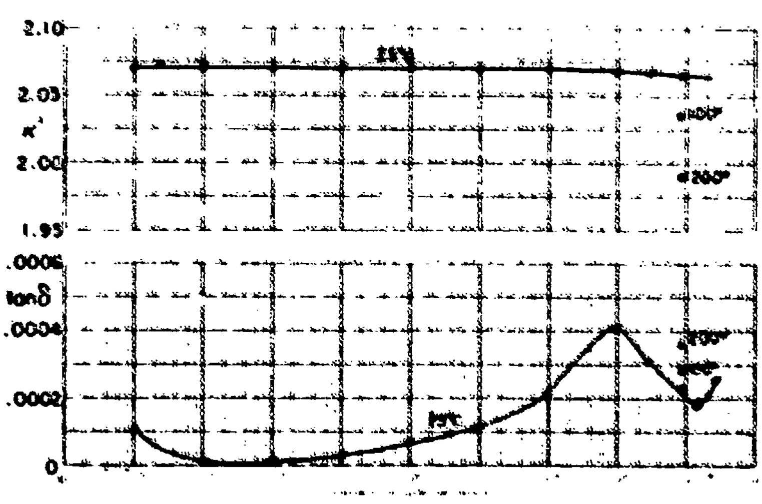
Density = 2.153 g/cm^3, at 25°C, 8.52 GHz
κ' = 2.058, tan δ = 0.00108

Teflon FEP (1964)





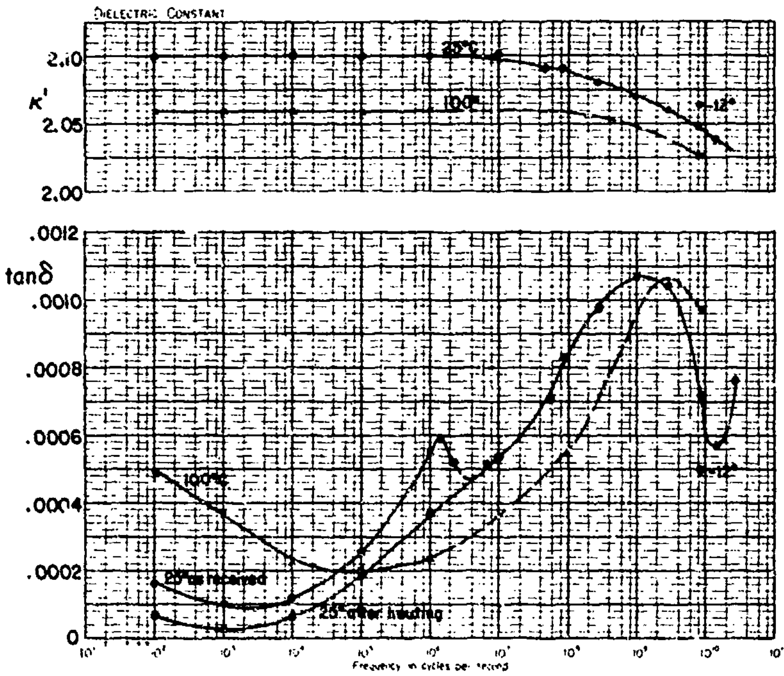
TFF-7 (1964)



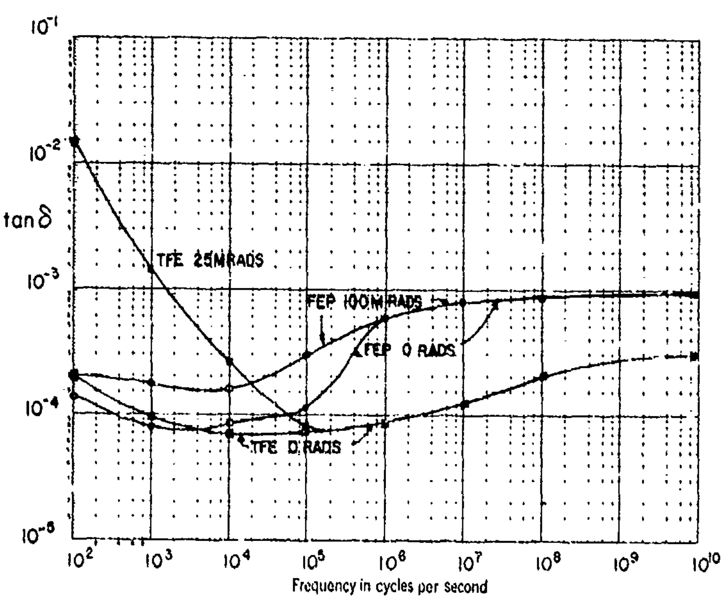
TFE-6C (1964)

Teflon T-100,*) Lot 38180
Density at 25°C = 2.152 g/cm^3

E. I. Dupont de Nemours and Co.



Teflon 100X (FEP) 1960 and TFE
Effect of Van De Graaff irradiation, 25°C



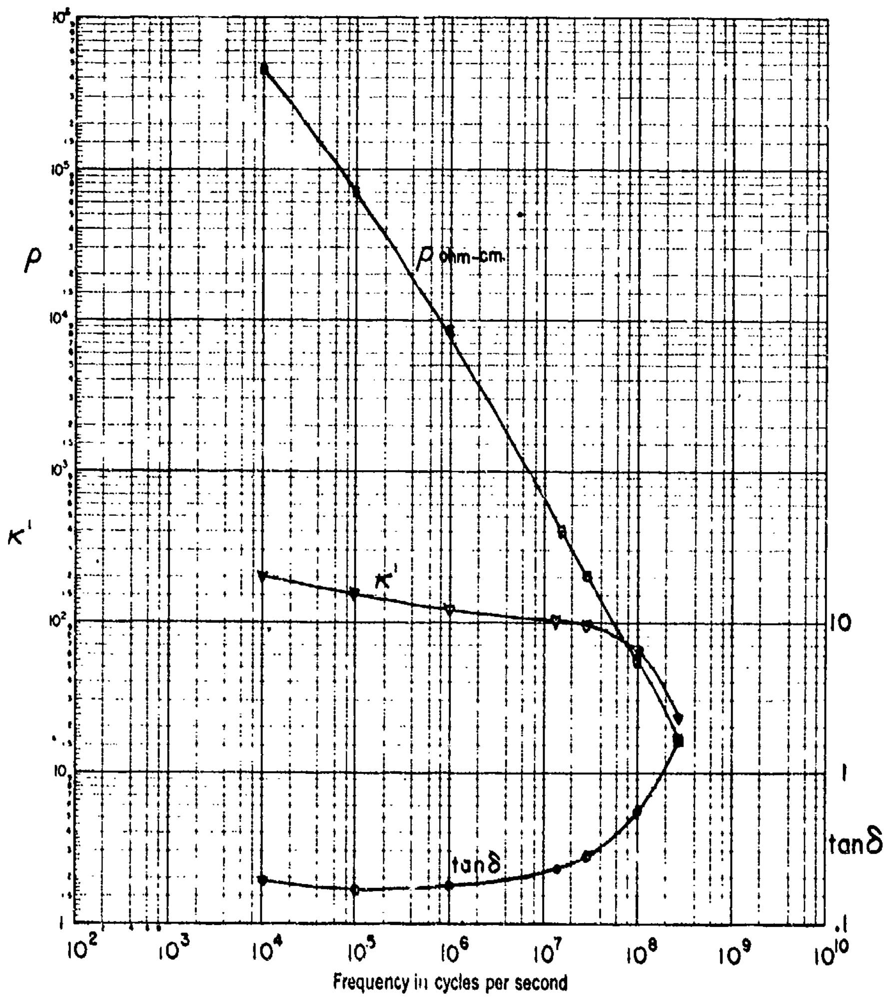
*) Electric data also apply to:

Teflon 9033, Lot 10601, density at 25°C = 2.147 g/cm^3

"Polyguide" Electronized Chemicals Corp.

		3 GHz		8.52 GHz		
		κ'	tan δ	κ'	tan δ	% wt. increase
As received	25°C	2.32	.00034	2.319	.00030	
	-48°C			2.320	.00017	
	74°C			2.300	.00040	
After 24 hrs. H_2O		2.32	.00047	2.320	.00038	.007

Emerson and Cumming A-19
graphite fiber loaded plastic, November 1966



"Eccogel" 1265

Emerson & Cuming

$T^{o}C$	Freq. (Hz) 60 κ	tan δ	10^3 κ	tan δ	10^6 κ	tan δ
25	7.60	.025	7.20	.0595	4.05	.1115
70					6.02	.0545
25 again					-	.0897
25 (after 24 hrs. in H_2O) wt. gain 1.08%					5.38	.128

"Eccofoam FH"

Emerson & Cuming

~~3.938~~ lb/cu.ft.

8.52 GHz κ	tan δ	24 GHz κ	tan δ
1.0856	.00161	1.0798	.00165

RTV-11

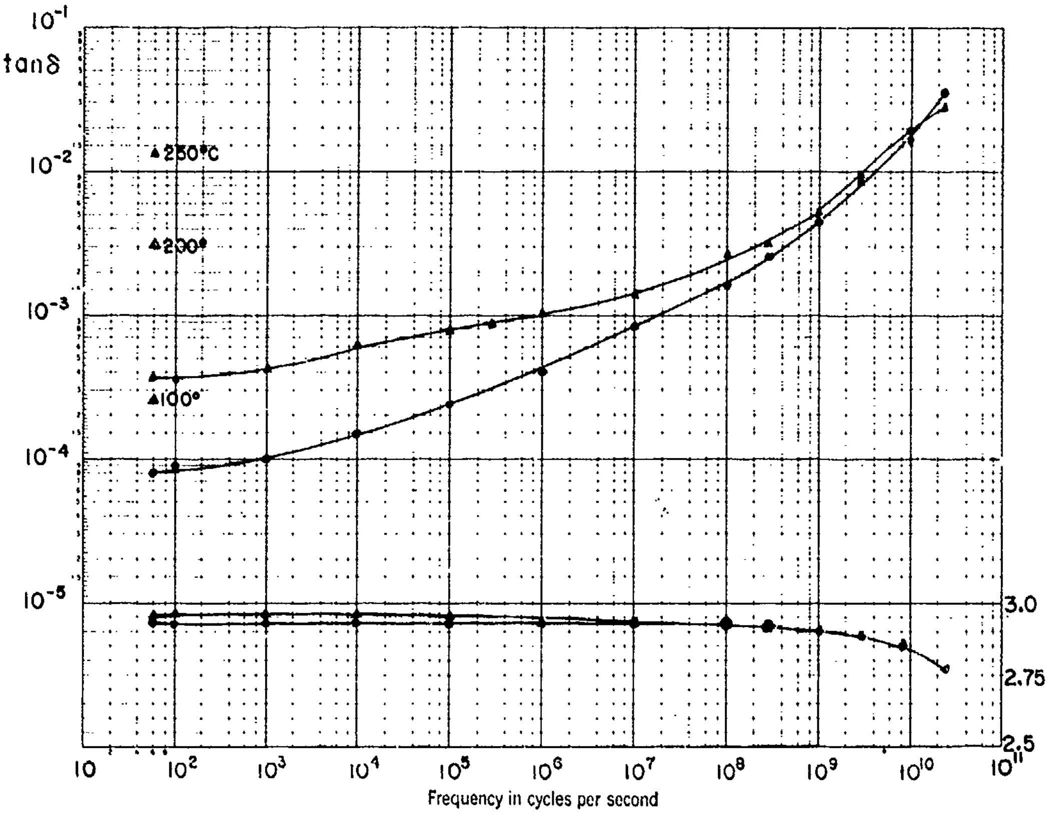
General Electric
Silicone Products Dept.

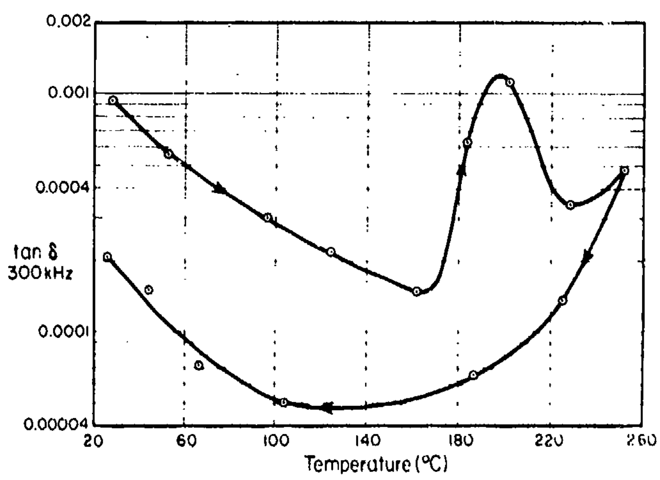
At 1 MHz

$T^{o}C$	κ	tan δ
25	3.25	.00285
70	3.05	.00372
25	-	.00242
25 (after 24 hrs in H_2O) wt. gain .035%	3.31	.00543

SE 900 Silicone Rubber General Electric

△ Sample cured 1 hr at 300°F, measured at 50% R. H.
○ Normal cure





Lexan General Electric

f(Hz)	κ'	tan δ
8.5×10^9	2.77	.00615
2.5×10^{10}	2.75	.00593

"3M" board 3-M

		3 GHz		8.52 GHz		% wt. increase
		κ'	tan δ	κ'	tan δ	
As received	25°C	2.32	.00038	2.316	.00037	
	-48°C			2.316	.00015	
	74°C			2.300	.00040	
After 24 hrs H_2O	25°C	2.32	.00060	2.316	.00043	

Scotchcast 221 3-M

At 1 MHz

T°C	κ	tan δ
25	3.06	.0273
70	3.73	.1373
25	-	.0245
25 (after 24 hrs. in H_2O) wt. gain .274%	3.12	.0352

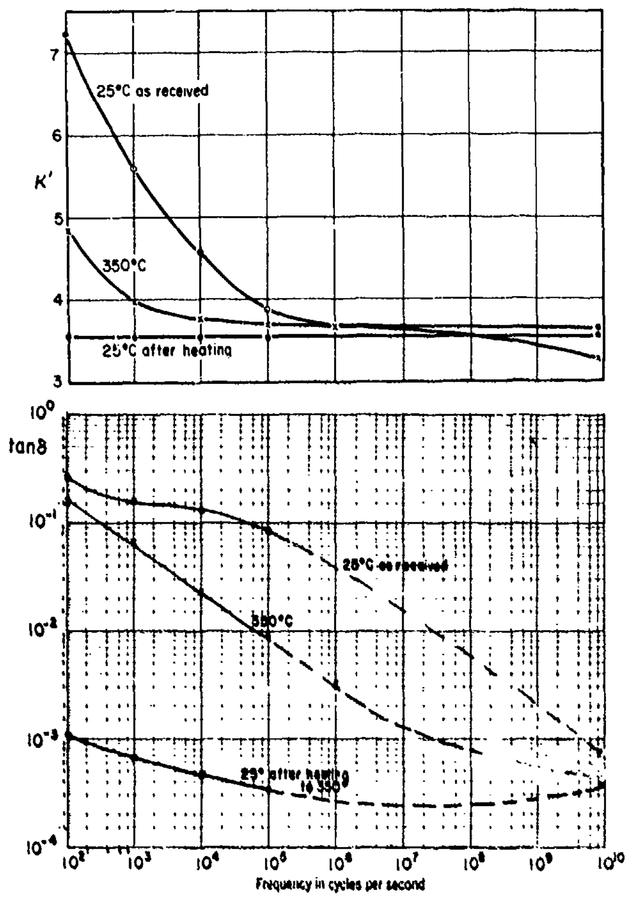
Polyimide foams Monsanto

At 8.52 GHz

	Density (lbs/cu.ft.)	T°C	κ	tan δ
HD-139	8.4	25	1.1439	.00277
		150	1.128	.00040
		304	1.118	.00045
		25	1.126	.0014
HD-140	16.7	25	1.301	.00507
		154	1.264	.00094
		307	1.260	.00121
		25	1.260	.00037
HD-144	21.8	25	1.412	.00635
		148	1.355	.00135
		303	1.382	.00190
		28	1.351	.0068

Polyurethane rigid foam, at 399 MHz				Nopco Chemical Corp.
	3.80 lbs/cu. ft		7.54 lbs/cu. ft	
$T^{o}F$	κ'	tan δ	κ'	tan δ
77	1.087	.00136	1.165	.00242
116	1.088	.00176	1.170	.00276
164	1.093	.00208	1.175	.00344

Fluorosint (1960) Polymer Corp.



Radar tape

Quantum Inc.
Lufbery Ave.
Wallingford, Conn.

At 14.2 GHz

T^oC	κ	tan δ
25	3.56	.0132
150	3.37	.0055
320	3.32	.0074
477	3.36	.0130

Plastics

Raytheon Company

Resin - "Bakelite" epoxy (Union Carbide)
- CY-178 epoxy (Ciba Products
Hardener - hexahydrothalic Anhydride, HHPA (Allied Chem.)

	73^oF			
	10^5 Hz		10^6 Hz	
Resin 100 parts	κ	tan δ	κ	tan δ
ERL-4221[a]	3.42	.0145	3.33	.0165
ERL-4221/ERRA-4090[b]	4.13	.0193	4.05	.0233
ERL-4289[c]	3.40	.0123	3.34	.0160
ERL-4259[d]	3.93	.0172	3.82	.0151
ERL-4259[e]	3.44	.0159	3.33	.0234
ERL-4221/ERRA-4090[f]	3.84	.0175	3.74	.0153
CY-178[g]	3.38	.0177	3.31	.0179
ERL-4221/ERRA-4090[h]	4.52	.0302	4.42	.0270

a. 90 parts HHPA, O-silica.

b. 65 parts HHPA, O-silica.

c. 65-HHPA, O-silica.

d. 65-HHPA, 115-silica.

e. 90 parts hardener liquid anhydride (Ciba), O-silica.

f. 65-HHPA, 85-silica.

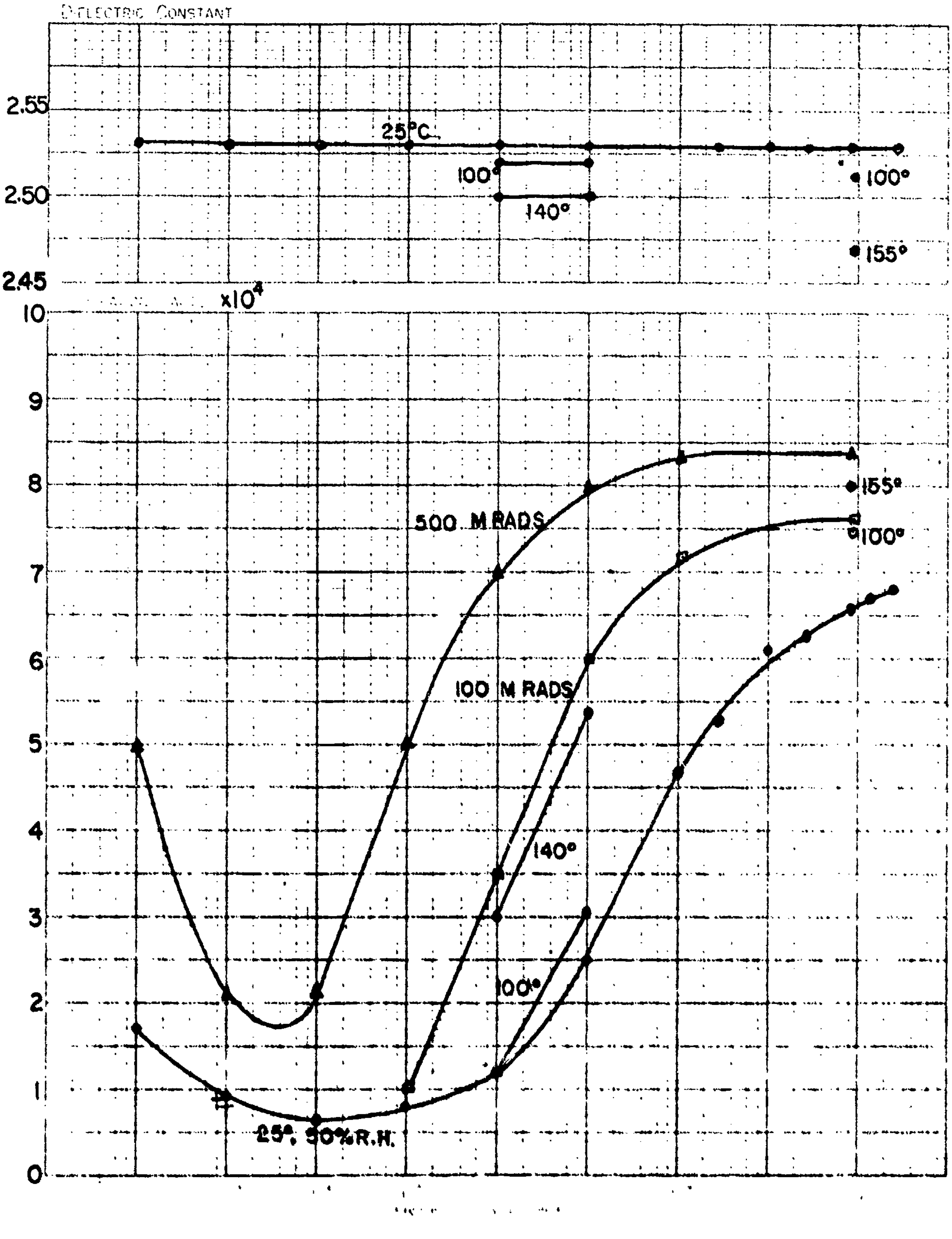
g. 65-HHPA, O-silica.

h. 65-HHPA, 118-silica.

Wm. Brand Rex Division
of American Enka Corp.

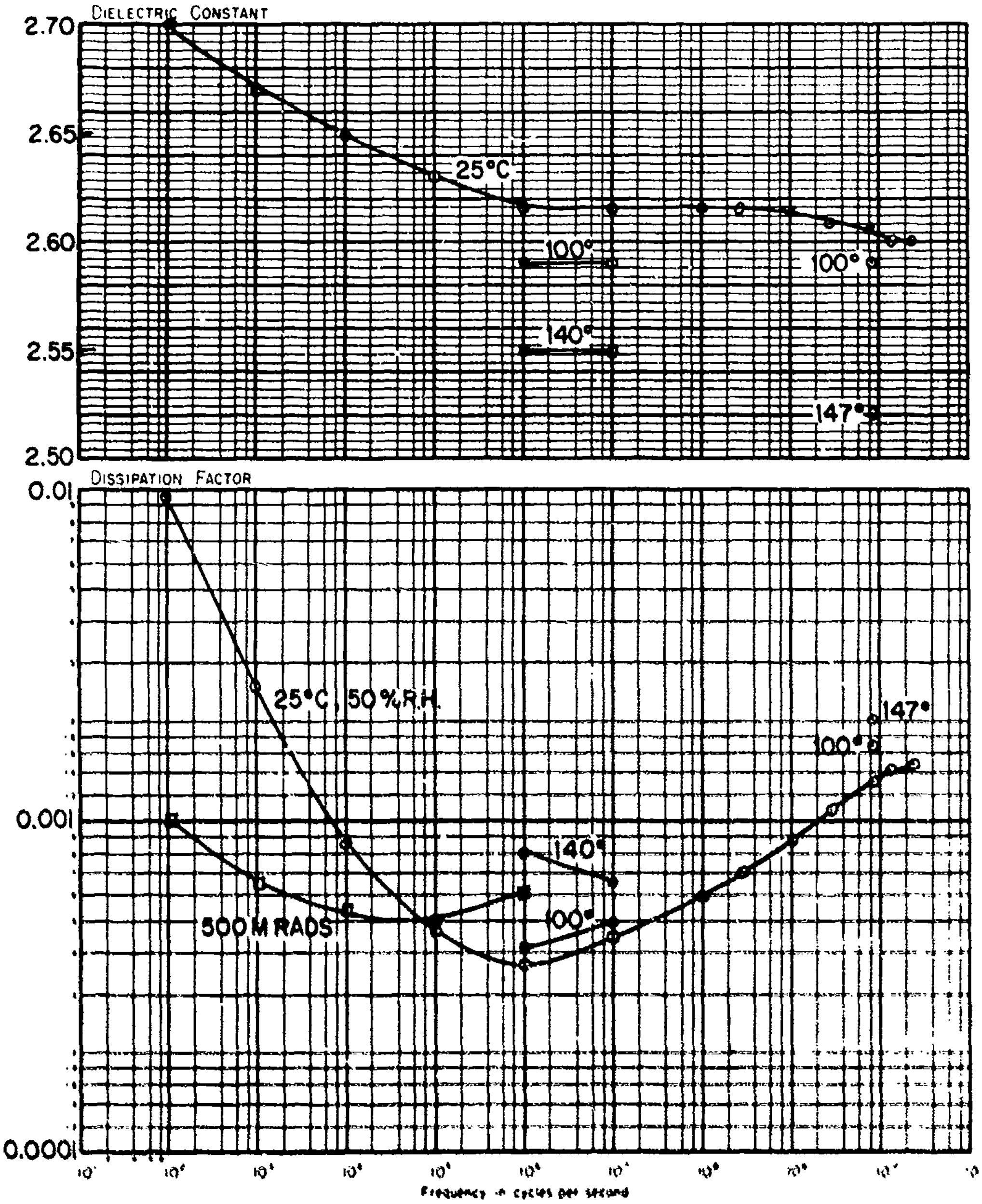
Rexolite 1422 (1964),

including effect of Van De Graaff irradiation (1960)



Rexolite 2200 (1964),

including effect of Van De Graaff irradiation (1960)

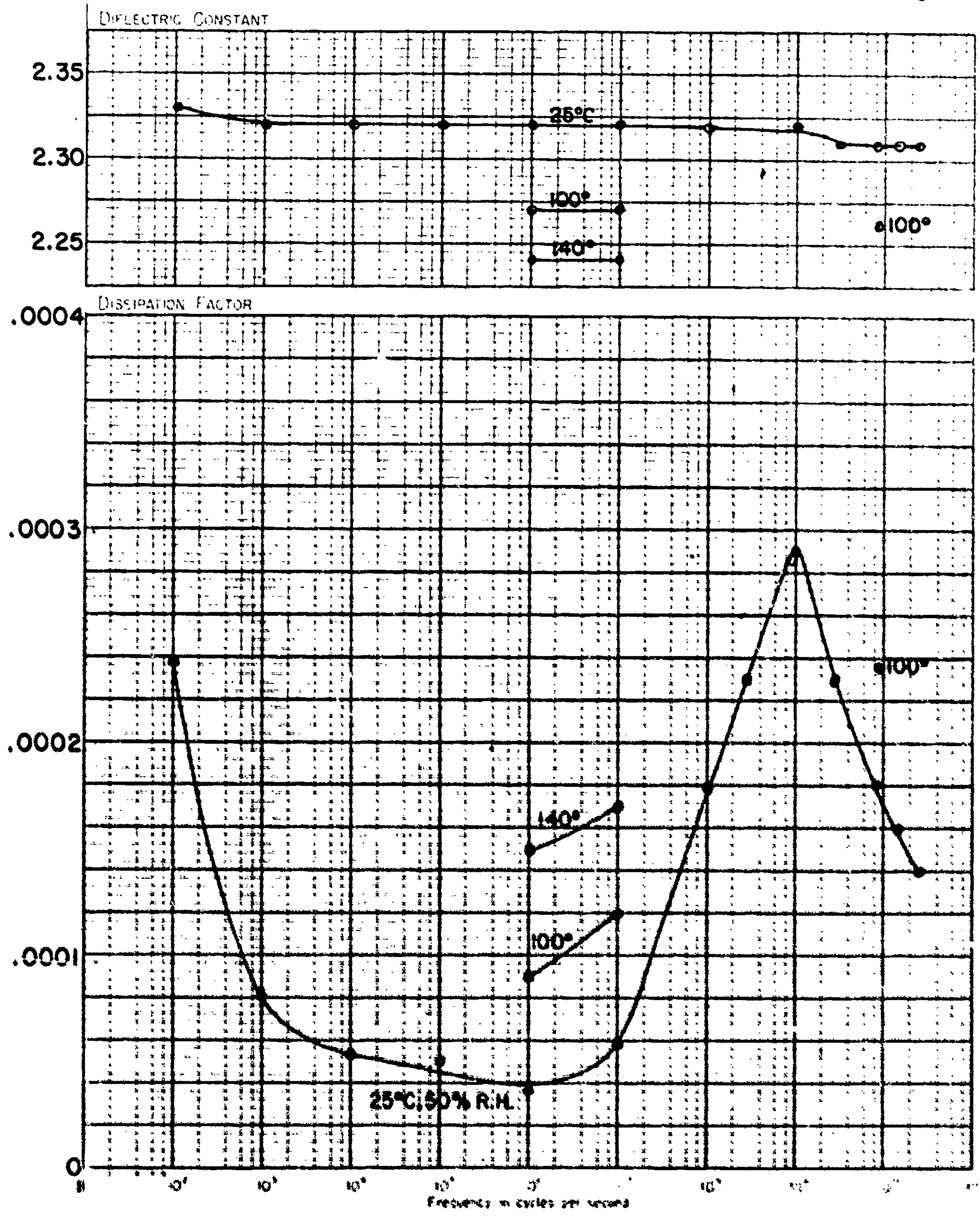


Rexolite 2200 (1965)

		3 GHz		8.52 GHz		% wt.
		κ'	tan δ	κ'	tan δ	increase
As received	$25^{o}C$	2.65	.00169	2.65	.00170	
	$-48^{o}C$			2.64	.00110	
	$74^{o}C$			2.645	.00209	
After 24 hrs. H_2O	$25^{o}C$	2.66	.0026	2.66	.00343	.055

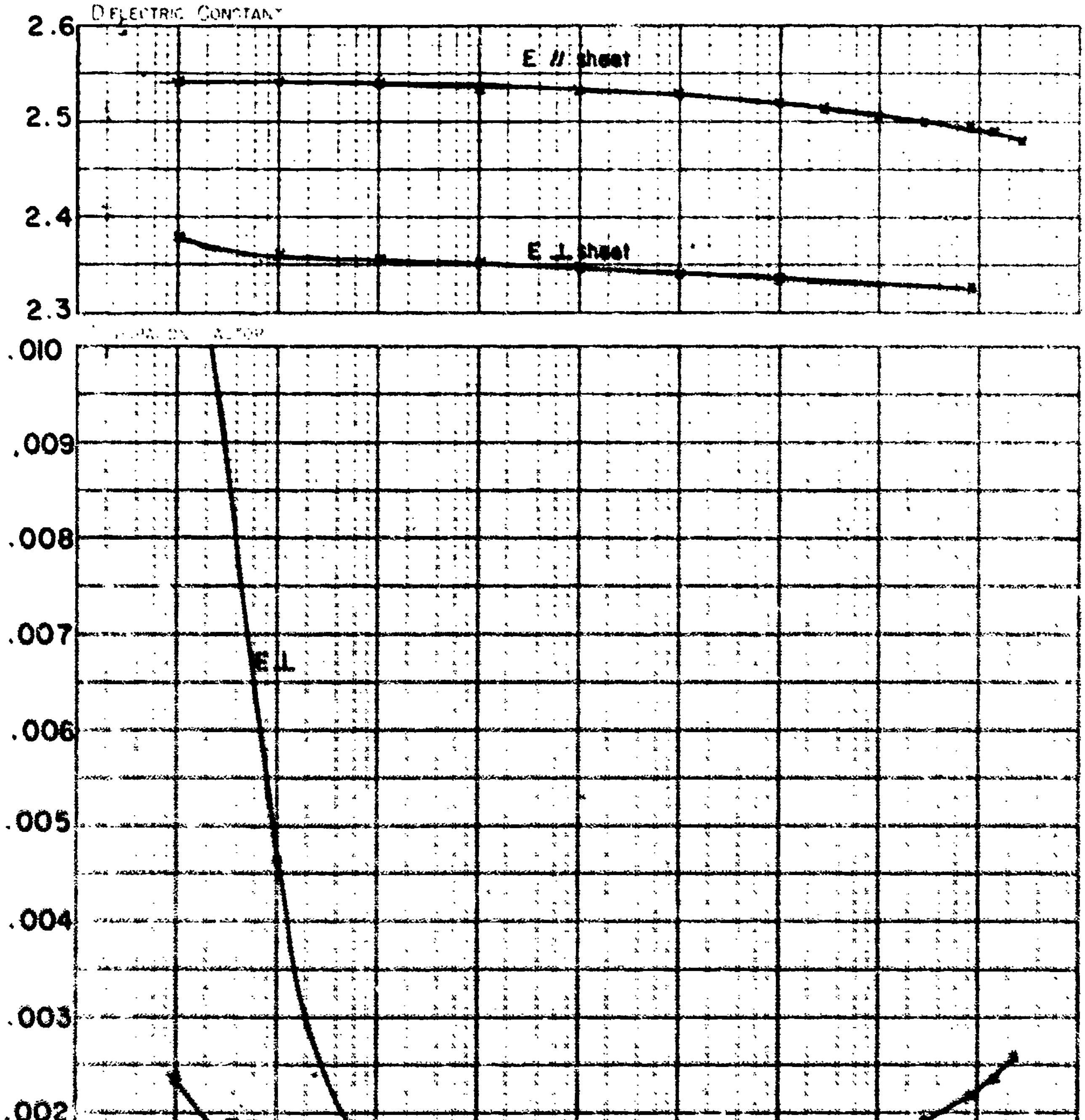
Rexolene P

Wm. Brand Rex Division
of American Enka Corp.



Duroid (1" thick sheet) Rogers Corporation

	3.7 GHz		4.3 GHz		
	E //		E ⊥		
$T^{o}C$	κ	tan δ	κ	tan δ	Cavity length (inches)
25	2.476	.00156	2.317	.00125	2.015
81.5	2.458	.00176	2.301	.00153	2.042
106.8	2.447	.00178	2.289	.00140	2.055
125	2.438	.00176	2.282	.00142	2.067
152	2.425	.00166	2.268	.00149	2.083
176	2.412	.00160	2.255	.00155	2.106
202	2.399	.00159	2.239	.00167	2.127
250	2.370	.00165	2.203	.00202	2.159
310	2.301	.00182	2.130	.0024	2.320
362	2.031	.00225	1.878	.0015	2.869

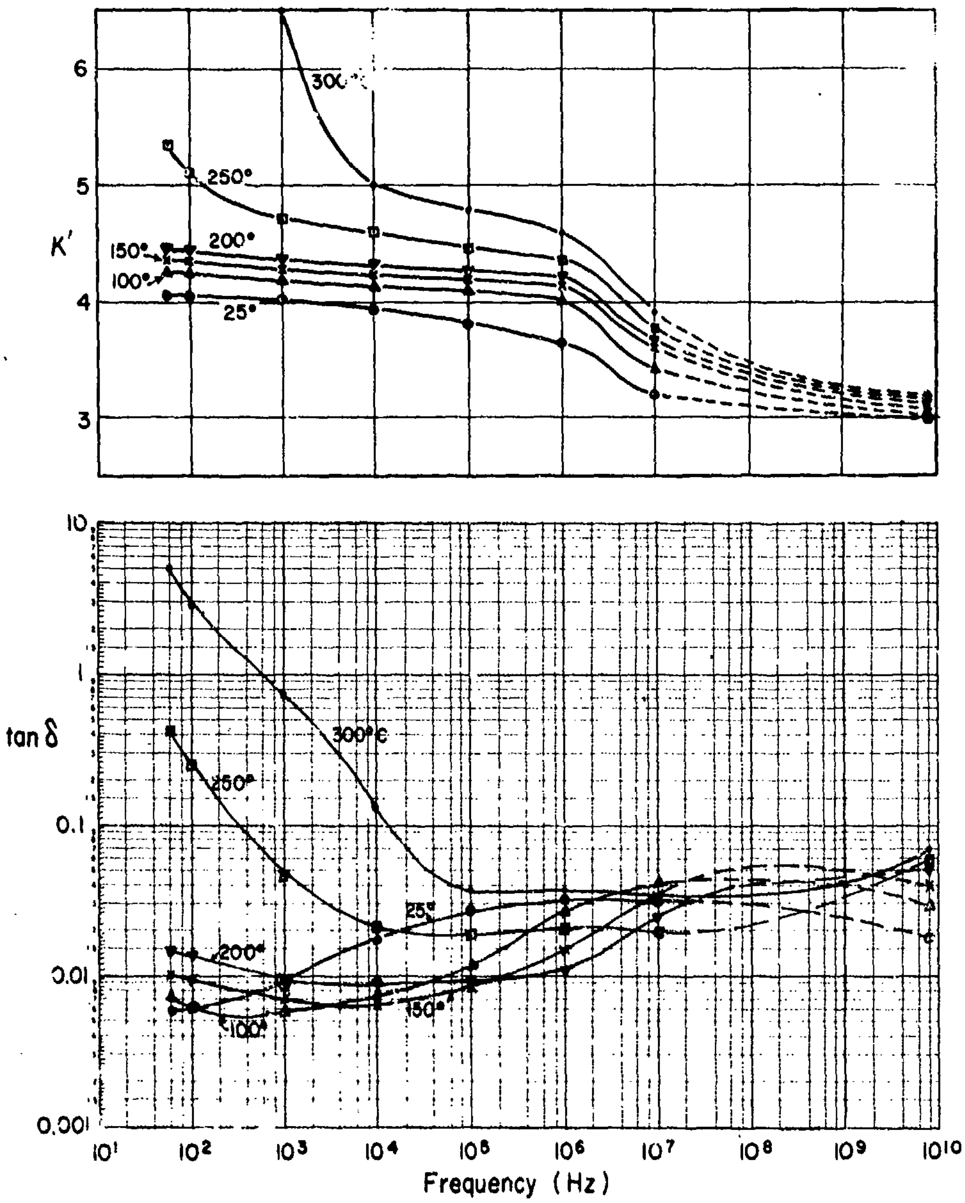

Dielectric Constant
2.6
2.5
2.4
2.3
E // sheet
E ⊥ sheet
.010
.009
.008
.007
.006
.005
.004
.003
.002
.001
0
E⊥
E//

Epon 828/PMDA casting Shell Chemical Company

156 pts. { Epon 828 epoxy 100 pts. by weight
PMDA (pyromellitic dianhydride) 56 pts. by weight

plus

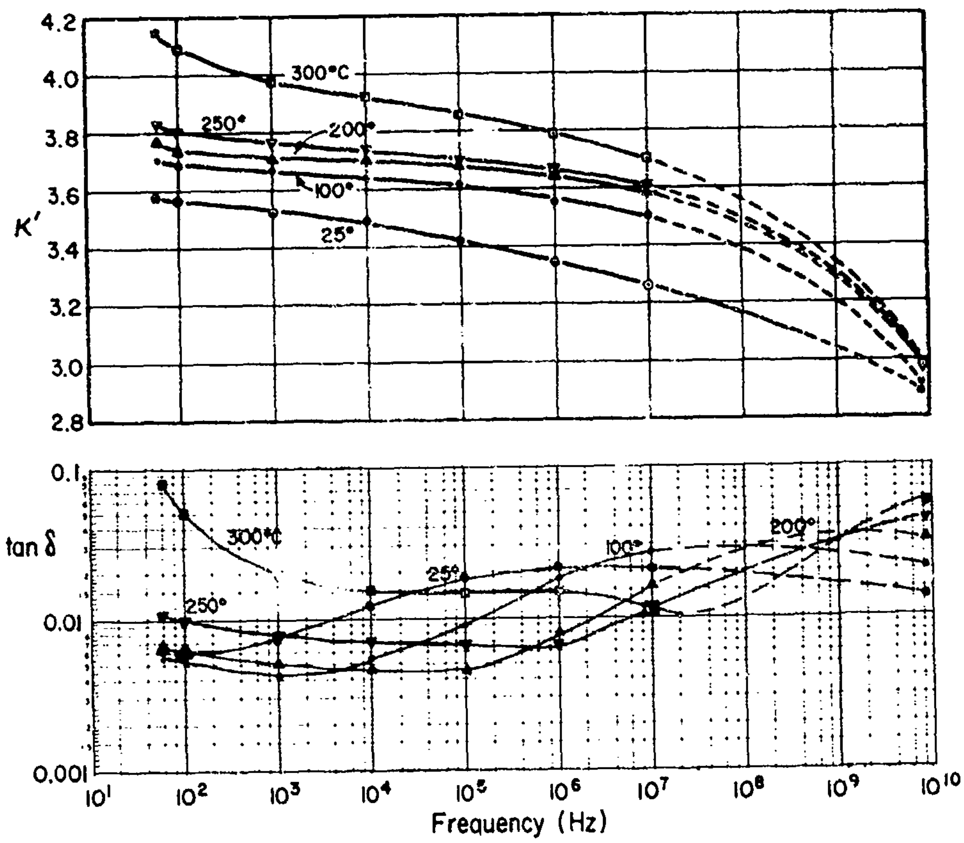
20 pts. { Tetrahydrofurfural alcohol 99 pts. by weight
Dicyandiamide 1 pt. by weight



Epon 828/PMDA casting Shell Chemical Company

Epon 828 epoxy 100 pts. by weight

PMDA (pyromellitic dianhydride) 31 pts. by weight



Polystyrene foam
Polyurethane foam

The Sippican Corporation

Sample	Hz	$5x10^4$	10^6	$6x10^7$	$3x10^8$	$1x10^9$
I, white polystyrene	κ	1.060	1.060	1.060	1.058	1.057
3 lbs/cu.ft.	D.F.	.000083	<.00002	<.0002	.00004	<.00005
II, blue polystyrene	κ	1.0368	1.0367	1.037	1.037	1.037
2 lbs/cu.ft.	D.F.	.000061	<.00002	<.0002	.0001	<.00005
III, polyurethane	κ	1.0846	1.082	1.080	1.078	1.077
4 lbs/cu ft.	D.F.	.00143	.00151	.0018	.00164	.00208
IV, polyurethane	κ	1.155	1.148	1.145	1.144	1.143
6 lbs/cu.ft.	D.F.	.00207	.00289	.0033	.00295	.00347

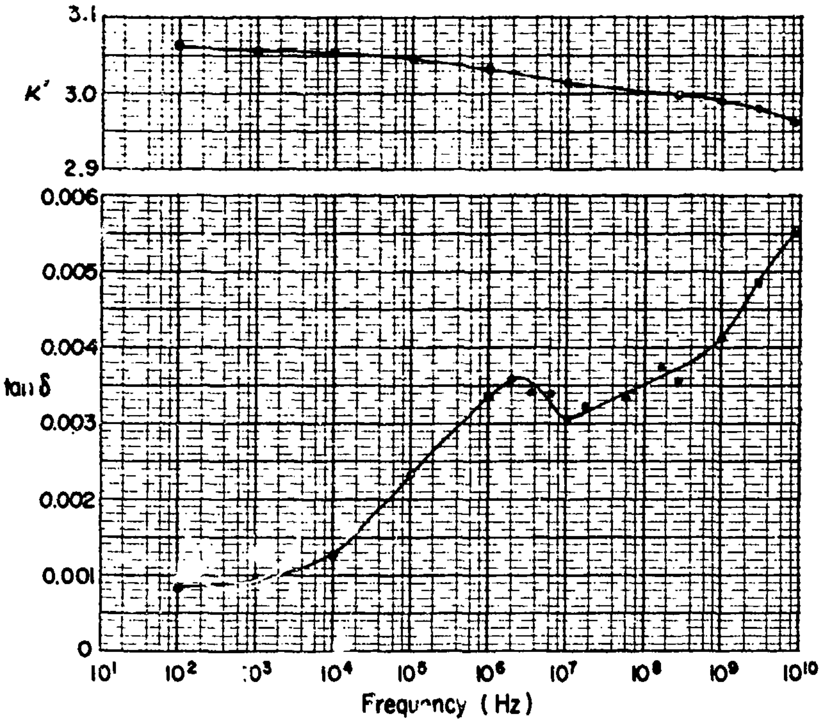
Tellite 3A

Tellite Corp.

	T^oC	κ'	tan δ	κ'	tan δ	% weight increase
As received	25	2.31	.00028	2.311	.00022	
	-48			2.318	.00020	
	74			2.294	.00027	
After 24 hrs H_2O	25	2.31	.00036	2.311	.0003[illegible]	.003

Polysulfone, 25°C, 50% R.H.

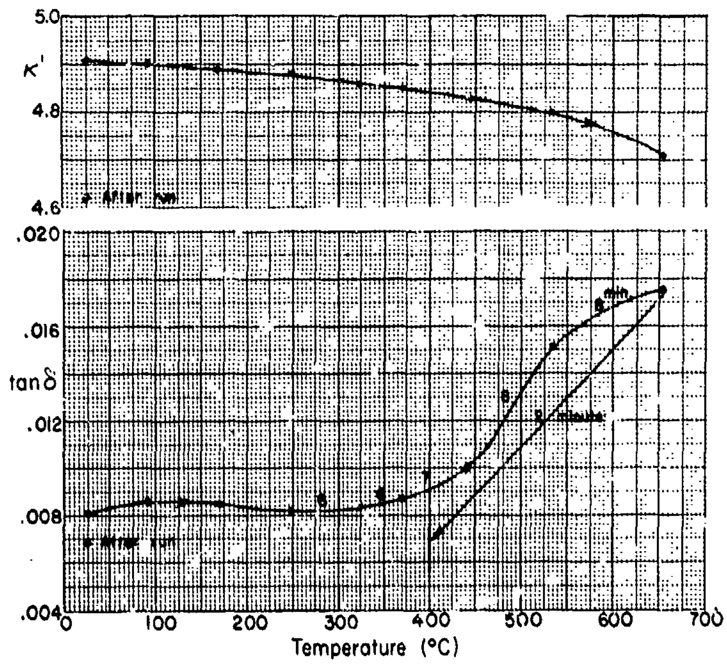
Union Carbide Corp.
Plastics Division

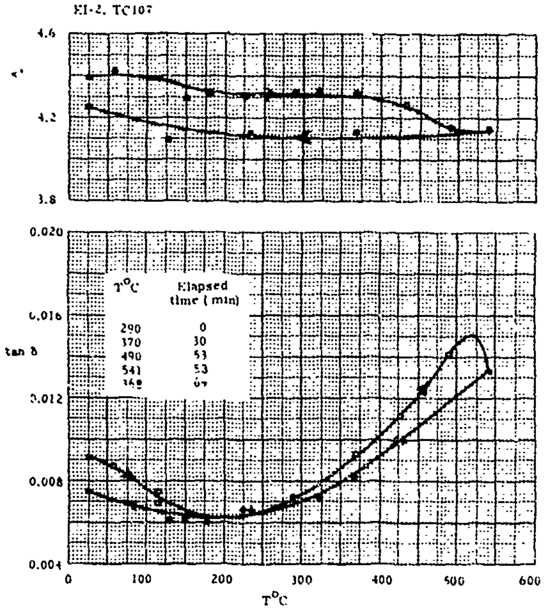


Fiberglass laminate

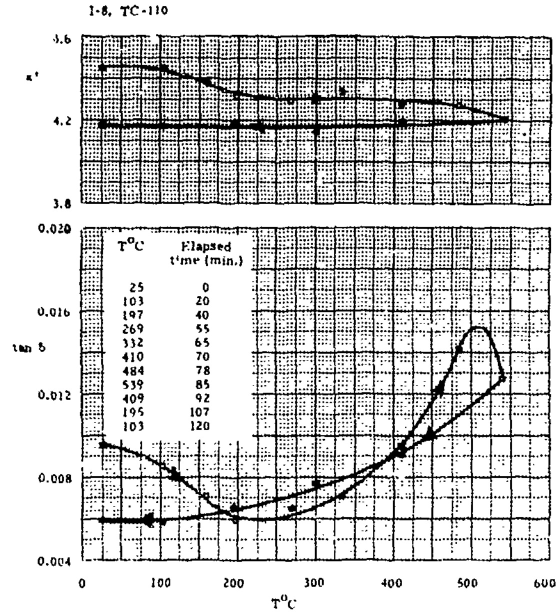
Air Force Materials Laboratory

with polybenzimidazole resin (approx. 24%)
density 1.949 g/cm^3

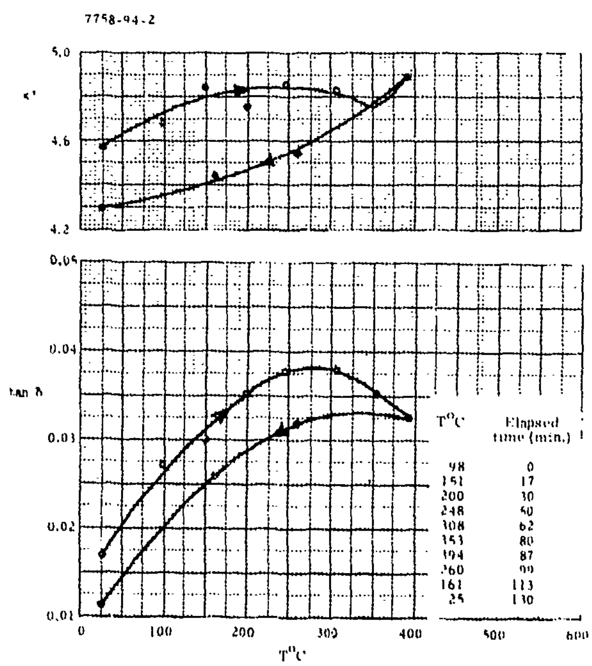




Fiberglass laminate with 181 glass cloth and a polyol cross-linked polyimide resin, 8.52 GHz



Fiberglass laminate with 181 glass cloth and a polyimide resin, 8.52 GHz



Fiberglass laminate with 181 glass cloth and epoxy resin, 8.52 GHz

IV. MISCELLANEOUS ORGANICS

Coal, powdered

Peabody Coal Division
Kennecott Copper

Room humidity, 8.5 GHz

Sample No.	κ'	κ''	tan δ	σ (ohm-cm)$^{-1}$	ρ (g/cm^3)
1-421	4.65	.892	.191	4.22×10^{-3}	.780
1-422	5.85	1.21	.206	5.73	.842
1-424	5.76	1.15	.199	5.42	.813
0-1071	4.84	1.02	.209	4.81	.759
1-429	4.33	.800	.184	3.68	.768
1-436	5.23	1.11	.211	5.24	.756
1-423	5.17	1.13	.217	5.35	.740
1-427	5.07	1.09	.215	5.17	.759
1-425	4.66	.885	.189	4.18	.792
0-1075	4.16	.788	.189	3.73	.775

Sample No.	Freq.,Hz	10^2	10^3	10^4	10^5	10^6	10^7
1-421	κ'	1626.	123.	40.8	21.1	15.5	9.11
ρ=.850	κ''	10886.	1122.	153.	24.2	9.56	3.02
	tan δ	6.69	9.10	3.75	1.14	.613	.331
	σ	6.0E-7	6.2E-7	8.5E-7	1.3E-6	5.3E-6	1.6E-5
1-422	κ'		720.	100.	39.4	18.7	11.1
	κ''		7368.	930.	92.8	18.8	5.12
ρ=.850	tan δ		10.2	9.28	2.36	1.01	.462
	σ		4.1E-6	5.1E-6	5.1E-6	1.0E-5	2.7E-5

Coal, single lump

Massachusetts Institute of Technology
National Magnet Laboratory

Frequency, Hz	10^6	8.5×10^9
κ'	-	8.4
κ''	-	2.47
tan δ	-	.294
σ	1×10^{-4}	.117

Balsa wood

The Sippican Corporation

Frequency, MHz	κ	tan δ
0.05	2.190	.123
1	1.928	.0614
60	1.727	.0620
300*	1.417	.046
1000*	1.404	.047

*) Electric field grain, others E along grain

Particle boards The Sippican Corporation

Sample	Freq., Hz	E ⊥ sheet 5×10^4	10^6	E ∥ sheet 3×10^8	10^9
1. U.S. Plywood fiber face	κ	3.16	2.94	2.91	2.69
	tan δ	.0345	.0410	.109	.105
2. U.S. Plywood fiber face, all phenolic	κ	3.48	3.02	2.85	2.66
	tan δ	.0745	.0582	.102	.096
3. U.S. Plywood Novoply	κ	3.12	2.98	2.87	2.67
	tan δ	.0261	.0320	.099	.100
4. Evans Products, MDF	κ	3.32	3.20	3.08	2.85
	tan δ	.0230	.0368	.106	.101
5. Evans Products, underlayment grade	κ	3.26	3.13	3.00	2.76
	tan δ	.0229	.0360	.110	.104

Wood products The Sippican Corporation

25°C, E in plane of sheet

Material	Freq.,Hz	5×10^4	5×10^5	3×10^6	1.8×10^7	3×10^7 *)	3×10^8
Pine board	κ	2.90	2.81	2.68	2.38	2.31	2.06
	tan δ	.0228	.037	.055	.081	.087	.090
Fir plywood	κ	3.18	2.97	2.78	2.54	2.47	2.25
	tan	.060	.068	.064	.064	.065	.074
Birch plywood	κ	2.87	2.74	2.62	2.38	2.32	2.16
	tan	.033	.041	.0505	.062	.063	.067
Marinite	κ	2.88	2.33	2.07	2.00	1.98	1.910
	tan	.49	.148	.054	.0219	.020	.0200

*) Values at 30 MHz are interpolated, not measured.

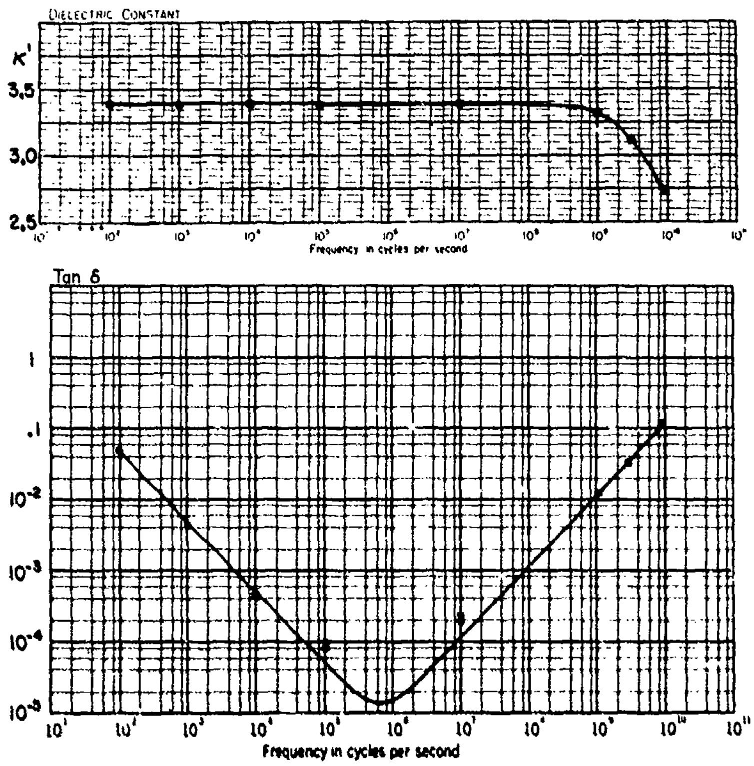
V. LIQUIDS

Fluorocarbon derivative P-1C — Allied Chemical Corporation

At 25°C

Freq. (GHz)	κ	tan δ
1	1.92	.0050
3	1.92	.0140
8.52	1.89	.029
14	1.87	.038

Dowtherm A — Dow Chemical

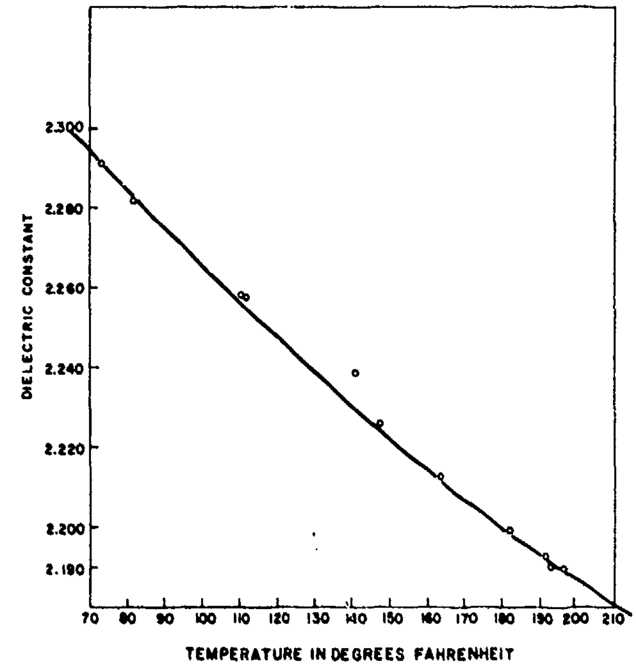


Fluorinated ethers, at 27°C — E. I. Dupont de Nemours & Co.

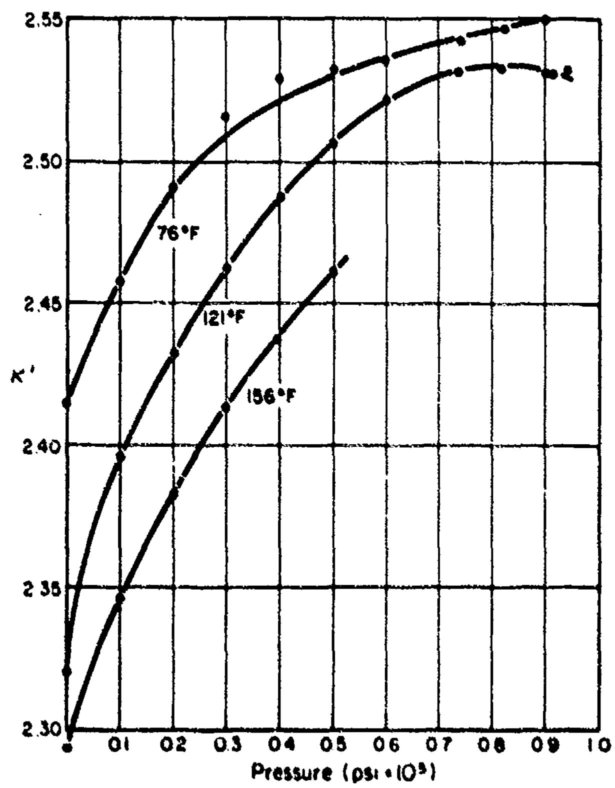
T°C = <6 to 28

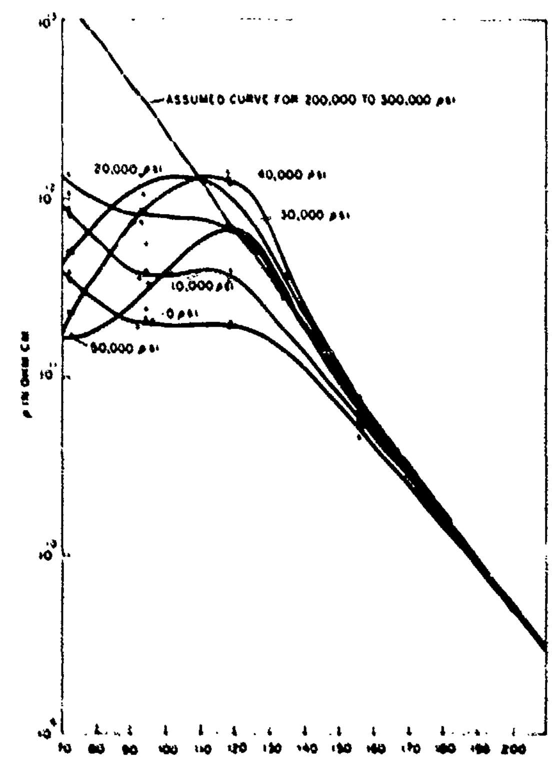
	FPS-1418		FPS-1419		FPS-1420	
	b.p. 148°C		b.p. 101°C		b.p. 153°C	
Freq. (Hz)	κ	tan δ	κ	tan δ	κ	tan δ
10^2	1.890	3×10^{-6}	1.859	1.6×10^{-5}	2.570	3.23×10^{-3}
10^5	1.890	3×10^{-6}	1.859	2×10^{-6}	2.570	1.6×10^{-5}
10^8	1.888	.00243	1.857	4.2×10^{-4}	2.53	.0126
10^9	1.851	.0142	1.833	.0042	2.420	.0952
3×10^9	1.838	.0124	1.832	.0075	2.213	.0995
8.5×10^9	1.797	.0068	1.798	.0084	2.026	.0907

Teresso V-78 Esso



Teresso V-78 (cont.)





Hercules, Inc.

DI-CUP
dicumyl peroxide

25°C

κ	tan δ
2.79	.0073
	.00081
	.000115
	.000064
	.00040
2.97	.0032
2.73	.0025
2.70	.0050
2.57	.0082
2.515	.0078
2.495	.0044

VUL-CUP
a,a[1]-bis(t-butyl peroxy) diisopropylbenzene

25°C

Freq., Hz	κ	tan δ
10^2	2.633	.0011
10^3		.00011
10^4		.000013
10^5		10^{-5}
10^6		.00005 ± 2
1.8×10^7		
6×10^9		
10^8	2.63	.005 ± 2
10^9	2.60	.0206
3×10^9	2.56	.0378
8.5×10^9	2.40	.056

99°C

Freq., Hz	κ	tan δ
10^9	2.26	.0116
3×10^9	2.24	.0184

Pennwalt Corp., Lucidol Div.

Lucidol

t-butyl perbenzoate

25°C

Freq., Hz	κ	tan δ
10^2	-	-
10^3	-	-
10^4	12.17	.17
10^5	12.17	.017
10^6	12.1	.0027
10^7	12.0	.0095
10^8	11.2	.0044
10^9	5.70	.252
3×10^9	4.07	.337
8.5×10^9	3.23	.460

Lupersol 130

2,5 dimethyl-2,5-di(t-butylperoxy)hexyne-3

25°C

Freq., Hz	κ	tan δ
10^2	2.656	.00123
10^3		.000123
10^4		.000012
10^5		.000023
10^6		.00012
10^7	2.655	.00121
10^8	2.65	.0066
10^9	2.56	.0235
3×10^9	2.50	.0344
8.5×10^9	2.39	.0505

99°C

κ	tan δ
2.33	.0076
2.32	.0154

Mullet oil — U.S. Bureau of Fisheries

	24 ± 0.5°C		10 ± 1°C	
Freq., GHz	κ	tan δ	κ	tan δ
1	2.54	.068	-	-
8.5	2.52	.0507	2.50	.0458
14	2.42	.0468	2.39	.0443
24		.0384	2.36	.0380

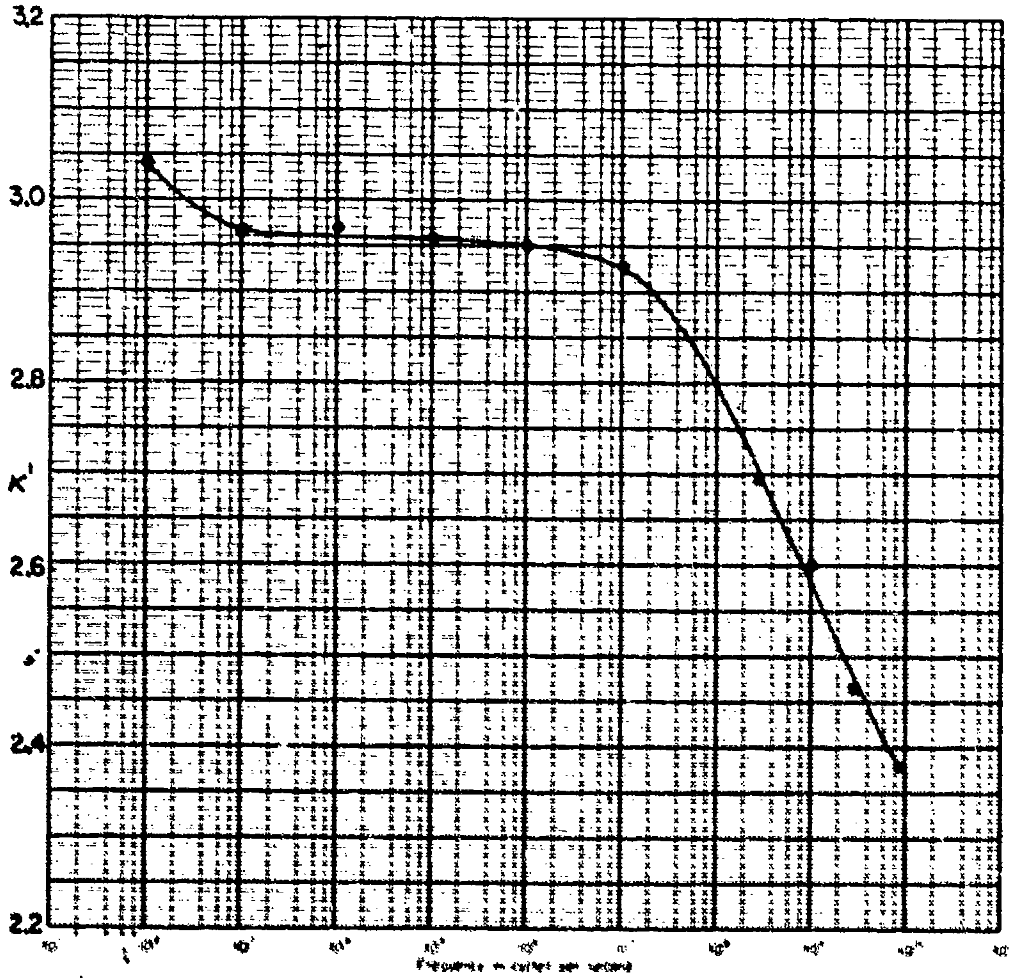
USP 333 — U.S. Peroxygen Div., Argus Chemical Corp.

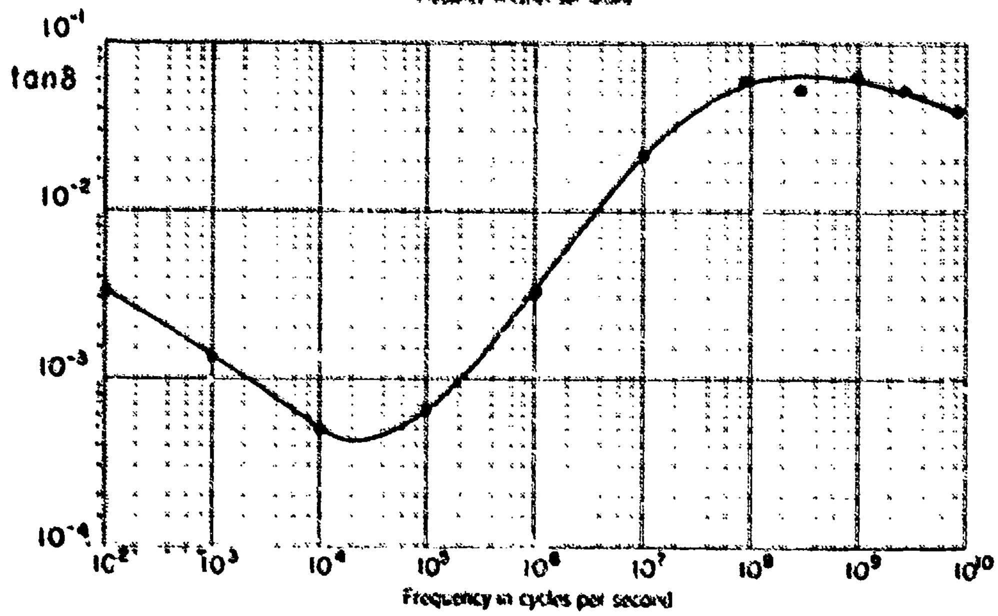
	25°C	
Freq., Hz	κ	tan δ
10^2	3.818	.0170
10^3	↓	.00170
10^4	↓	.00017
10^5	↓	.000027
10^6	↓	.00021
10^7	3.81	.00157
10^8	3.75	.0146
10^9	3.60	.0842
3×10^9	3.30	.130
8.5×10^9	2.80	.1735

Lupersol 101 — Wallace & Tiernan Inc.
2,5-dimethyl-2,5-di(t-butylperoxy)hexane

Freq., Hz	κ	tan δ
	at 25°C	
10^4	2.66	.000088
10^5	2.66	.000144
10^6	2.66	.000053
10^7	2.65	.00049
10^8	2.64	.0050
10^9	2.62	.0217
3×10^9	2.58	.0387
8.5×10^9	2.41	.057
2.4×10^{10}	2.26	.045
	at 99°C	
10^9	2.02	.0040
3×10^9	2.02	.0068

Kremax Armour





Frozen lean steak

T°F	150 MHz κ	150 MHz tan δ	1000 MHz κ	1000 MHz tan δ	3000 MHz κ	3000 MHz tan δ
-75	3.42	.022	3.33	.0164	3.22	.0105
-60	3.61	.040	3.42	.026	3.40	.014
-50	3.70	.058	3.46	.036	3.44	.0185
-40	3.82	.072	3.51	.050	3.46	.024
-30	3.92	.094	3.60	.066	3.55	.032
-20	4.18	.102	3.80	.089	3.70	.040
-10	4.50	.138	4.10	.12	3.80	.054
0	5.33	.18	4.40	.165	3.95	.076
10	6.35	.24	5.18	.223	4.37	.108
20	9.55	.39	9.50	.203	7.30	.174
30	33	.60	20.8	.254	8.40	.250
40	53.5	.22	33.0	.32	8.30	.208
50	53.0	.21				

Vacuum-dry lean beef

T°F	150 MHz κ	150 MHz tan δ	1000 MHz κ	1000 MHz tan δ	3000 MHz κ	3000 MHz tan δ
-60			1.495	.00320	1.471	.00335
-40	1.535	.0060	1.497	.00375	1.473	.00395
-20	1.548	.0080	1.502	.00446	1.475	.0047
0	1.562	.0102	1.511	.00535	1.480	.0057
20	1.582	.0132	1.520	.0066	1.483	.0068
40	1.60	.0168	1.530	.0080	1.490	.0082
60	1.62	.0216	1.542	.0096	1.500	.0099
80	1.648	.0264	1.558	.0111	1.509	.0119
100			1.571	.0127	1.522	.0138
120			1.587	.0143	1.535	.0147
140			1.604	.0160	1.545	.0175
160			1.622	.0176	1.560	.0193
180			1.612	.0198	1.590	.0214

Potato (Maine, 78.9% H_2O), 25°C

f (GHz)	κ'	tan δ
.3	130	.83
1	87	.39
3	81	.38

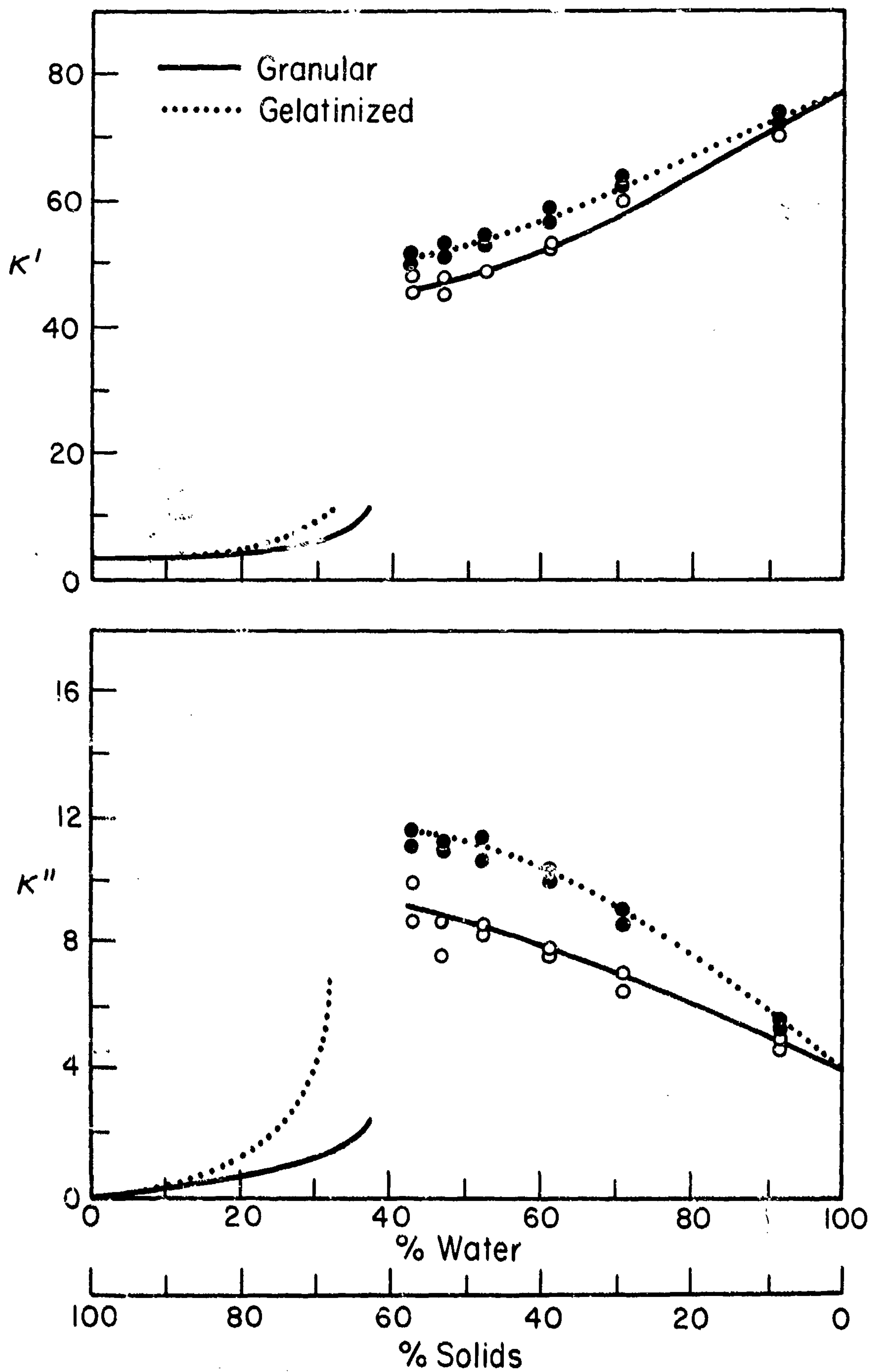
Potato flakes, density 0.284

f (GHz)	κ'	tan δ
.3	1.50	.034
1	1.485	.030
3	1.47	.029

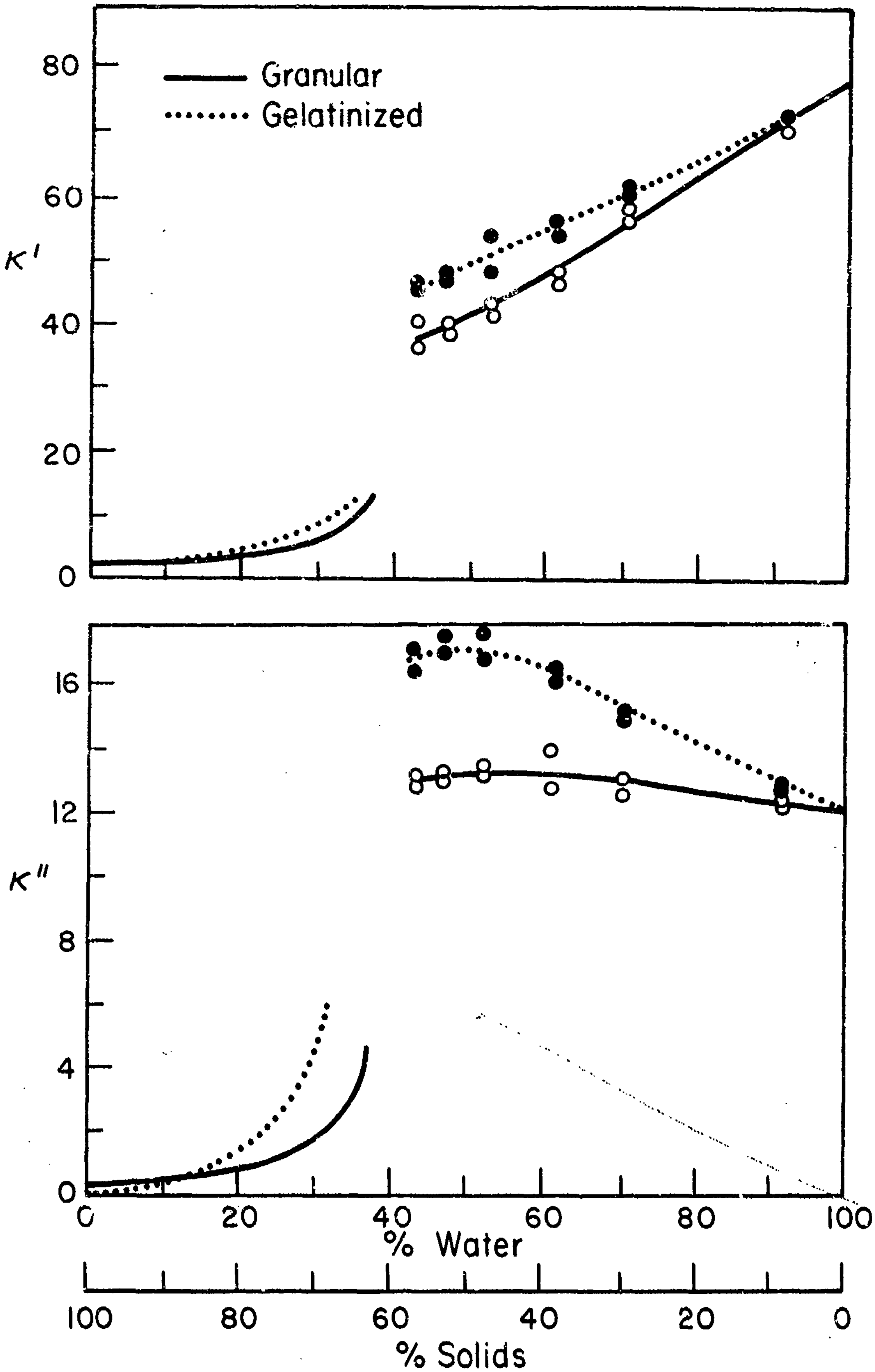
Potato chips

	f (GHz)	κ'	tan δ
partly cooked	1	5.76	.36
	3	5.18	.55
cooked	1	1.89	.034
	3	1.86	.036

Potato starch,
granular and gelatinized, at 1.0 GHz, 25°C



Potato starch,
granular and gelatinized, at 3.0 GHz, 25°C



	Nescafe			Nestea		
f (Hz)	κ'	tan δ	σ	κ'	tan δ	σ
10^2	1.557	.0115	9.93×10^{-13}	1.290	.00442	3.17×10^{-13}
10^3	1.529	.0113	9.58×10^{-12}	1.281	.00384	2.73×10^{-12}
10^4	1.490	.0103	8.52×10^{-11}	1.276	.00301	2.13×10^{-11}
10^5	1.488	.0090	7.43×10^{-10}	1.270	.00245	1.73×10^{-10}
10^6	1.471	.0089	7.27×10^{-9}	1.267	.00230	1.62×10^{-9}
10^7	1.453	.0093	7.52×10^{-8}	1.260	.00196	1.37×10^{-8}
3×10^8	1.432	.0106	2.53×10^{-7}	1.24	.0023	4.75×10^{-7}
10^9	1.39	.0098	7.57×10^{-6}	1.22	.0024	1.63×10^{-7}
3×10^9	1.36	.0093	2.11×10^{-5}	1.21	.0026	5.25×10^{-6}
8.5×10^9	1.34	.0086	5.65×10^{-5}	1.20	.0033	1.87×10^{-5}
	density 0.241 g/cm^3				0.126 g/cm^3	

Eggwhite

Frequency	κ'	tan δ	ρ
3×10^9	35	.5	
9.2×10^9	13	1.1	
10^4, 10^5			35

Bread

1.2×10^7	11	3.35	

Dough

10^7	2×10^5	2.25	1